EFFECTS OF HEATED DISCHARGE AND ENTRAINMENT ON BENTHOS IN THE VICINITY OF THE J. H. CAMPBELL PLANT, EASTERN LAKE MICHIGAN, 1978-1981

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INTRODUCTION

The J.H. Campbell Plant is comprised of three coal-fired operational units. Units 1 and 2 use Lake Michigan water drawn through Pigeon Lake for cooling purposes. Unit 3 draws cooling water from an intake located in approximately 11 m of water (1.1 km offshore) in Lake Michigan. Beginning in September 1980, heated water from all three units was discharged through a common offshore structure located in approximately 6 m of water (0.3 km offshore).

Concurrent with reports on larval, juvenile, and adult fish (Jude et al. 1978, 1979, 1980, 1981, 1982), this is the last in a series of five reports on the benthos that began in 1977. Previous reports (Jude et al. 1978; Winnell and Jude 1979, 1980, 1981) have dealt with annual, monthly, depth, and regional density fluctuations of the benthos and grain size analysis of substrates occurring in the vicinity of the Campbell Plant from the perspective of each particular year. Comparisons were made to determine the relevance and longevity of regional trends as related to plant operation and general lake-wide distribution (for more on lake-wide distributions in addition to Winnell and Jude, see Powers and Robertson 1965; Robertson and Alley 1966; Hiltunen 1967; Alley 1968; Mozley and Garcia 1972; Mozley and Alley 1973; Mozley 1974, 1975; Alley and Mozley 1975; Mozley and Winnell 1975; Mozley and Howmiller 1977; Nalepa

and Quigley 1980; Nalepa and Robertson 1981). When compared with lake-wide distributions, we have observed some similarities (dominance of amphipods, oligochaetes, and chironomids) and dissimilarities (very high abundance of Pontoporeia hoyi). Other investigations near the Campbell Plant have indicated some regional differences (Truchan 1970; Consumers Power Company 1975). We noted during preoperational years (1978-1980) that, while depth and temporal factors accounted for much of the variability in benthic distributions, regional differences did exist and needed to be monitored. With the inclusion of the first and only full operational year for which benthic data will be collected, we were able to employ a modification of the statistical design proposed by Winnell and Jude (1980). The analysis of variance (ANOVA) design was modelled after a similar 8-yr design (Johnston 1974) used to test for a plant effect at the D.C. Cook Nuclear Power Plant located 113 km south along the shoreline of Lake Michigan [unpublished data, Great Lakes Research Division (GLRD)]. The modified statistical design was applied to benthic density fluctuations found in the 3 to 15-m depth range sampled from 1978-1981 near the J.H. Campbell Power Plant. We found no differences among density fluctuations at the ANOVAs' levels of sensitivity. In addition, we concluded that entrainment of malacostracans from pumping of cooling water via intake structures located in Lake Michigan had no apparent effect

on lake populations of malacostracans or on overall lake ecology.

METHODS

LAKE MICHIGAN BENTHIC FIELD SURVEYS

Benthos Field Survey Design

The survey was composed of 10 stations located along two transects perpendicular to the eastern shoreline of Lake Michigan near the J.H. Campbell Power Plant, Ottawa County, Michigan (Fig. 1). Along each transect, stations were located at 3-, 6-, 9-, 12-, and 15-m depths. The first transect represented the treatment area (inner region) located 0.16 km north of the offshore intake and discharge structures. The second transect represented the reference area (outer region) located 5.0 km north of the offshore intake and discharge structures. The survey design was the same during 1979, 1980, and 1981.

Benthos Collection and Processing

Benthic macroinvertebrate samples were collected on 13 April, 13 July, and 8 October 1981. Sixty samples per month were collected from the University of Michigan's R/V Mysis. Sediment samples, which were collected during 1979 and 1980, were not collected during the 1981 field season.

Benthic macroinvertebrates were collected with a triplex (three-chambered) Ponar grab sampler (Mozley and

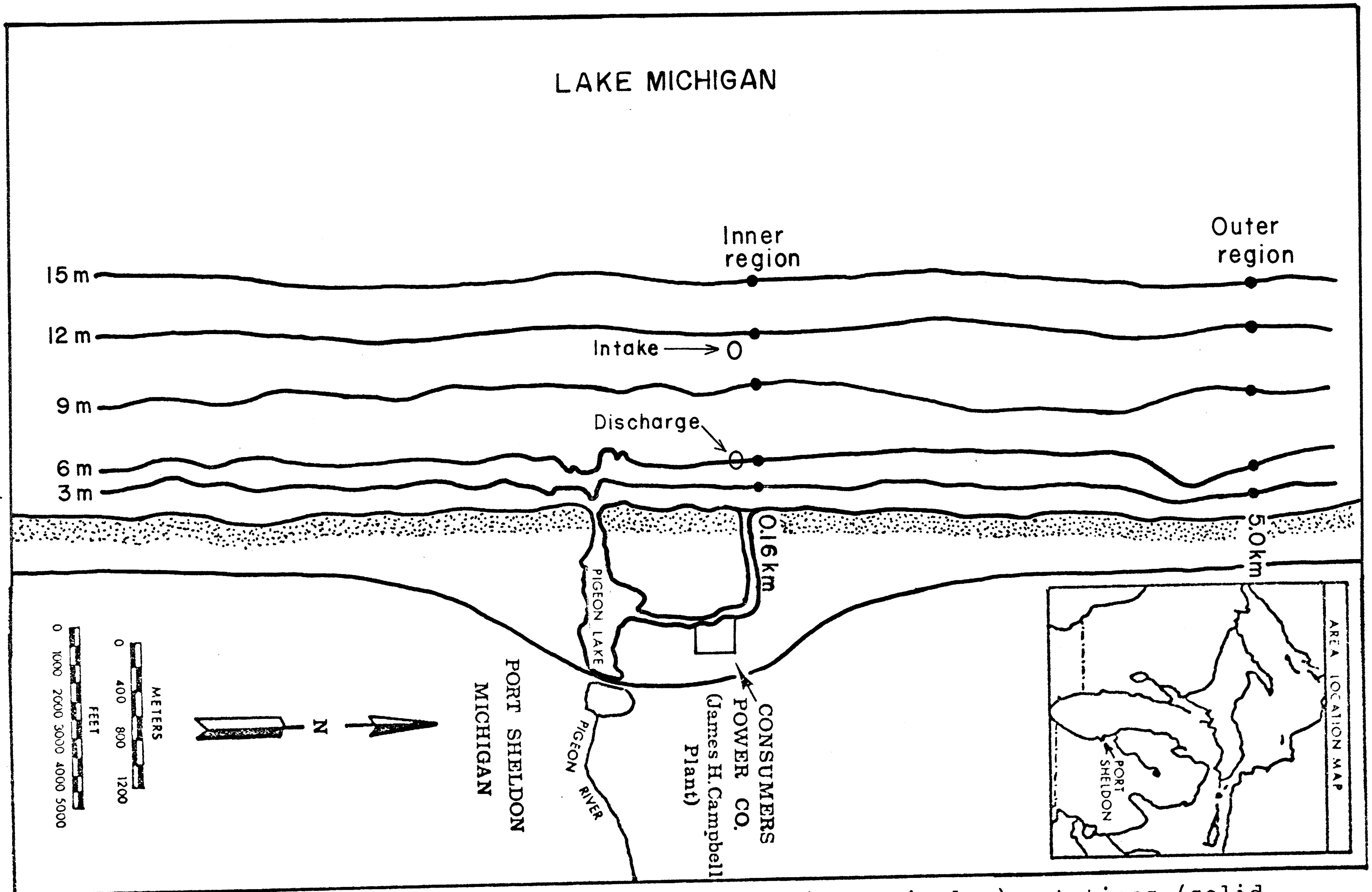


Fig. 1. Location of intake and discharge structures (open circles), stations (solid dots), regions (Inner = treatment area located 0.16 km north of intake and discharge structures, Outer = reference area located 5.0 km north of intake and discharge structures), and depths sampled in the 1981 benthos survey near the J. H. Campbell Plant, eastern Lake Michigan.

Chapelsky 1973). Each chamber of the Ponar samples 0.0165 m^2. Contents of one side chamber were used to estimate numbers of benthic macroinvertebrates occurring in a square meter of lake bottom. Six replicates were collected to estimate benthic populations at a station on each sampling date.

The portion of the sample used to estimate benthic macroinvertebrates was placed in a "funnel-shaped hopper" (see Mozley 1975 for details) aboard the ship. Samples were washed through a 0.2-mm mesh net to concentrate animals and remove excess sediment and debris. Concentrated samples were stored in labelled 0.5-liter Mason jars and preserved with carbonate-buffered, 4% formaldehyde solution. Samples were returned to the GLRD Benthos Laboratory for sorting and identification.

Sorting and initial identification of organisms were performed using dissecting microscopes (3-30X). Specimens unidentified at the genus/species level were mounted on slides with Amman's lactophenol clearing medium and identified using compound microscopes (40-1,000X).

Initial generic identification of chironomids was determined using an unpublished trial key to the chironomids (A.L. Hamilton and O.A. Saether, personal communication, Freshwater Institute, Winnipeg, Manitoba, Canada and Zoological Museum and Department of Morphology, Systematics and Animal Ecology, University of Bergen, Bergen, Norway). Where species were determined for chironomid genera,

"cf." refers to uncertain larval identification at the species level. Most species designations concur with reared specimens from the D.C. Cook Nuclear Power Plant, southeastern Lake Michigan (see Mozley 1975), which are maintained in the GLRD Benthos Laboratory's permanent collection. However, as none of the chironomid larvae from the Campbell Plant have been reared, identifications at the species level have been assigned the uncertainty designator "cf.". The designator "gr." refers to a "group" of species undeterminable from larvae and was associated with the genera Chironomus and Paracladopelma. Morphology and taxonomy of other chironomid genera and species were determined from the following references: Lenz (1954), Roback (1957), Curry (1958), Beck and Beck (1969), Saether (1969, 1971, 1973, 1975, 1976, and 1977), Hirvenoja (1973), Maschwitz (1975), Jackson (1977), and Soponis (1977).

Naidids were identified using Hiltunen's key to the naidids (see Hiltunen and Klemm 1980). Tubificids were identified using an unpublished key to aquatic oligochaetes of the Great Lakes (J.K. Hiltunen, personal communication, Great Lakes Fishery Laboratory, U.S. Fish and Wildlife Service, Ann Arbor, Michigan). Gastropods and pelecypods were identified using a key to the mollusks of the Great Lakes (Mackie et al. 1980). Amphipods were identified using the keys developed by Holsinger (1976) and Pennak (1978).

Statistical Design, Sensitivity of the ANOVA, and Determination of a Plant Effect

The statistical design initially proposed to determine plant effect (in terms of heated effluent discharged into Lake Michigan) and relative sensitivity of the design to population changes was a balanced mixed-model, nested analysis of variance (ANOVA). This design originated from an 8-yr design developed by Johnston (1973, 1974) and employed at the D.C. Cook Nuclear Power Plant (unpublished data, GLRD). The present application was based on a 4-yr design with 2 preoperational yr (1978 and 1979) and 2 operational yr (1980 and 1981) anticipated, making our design a balanced modification of the 8-yr design. A balanced design was necessary not only for computational purposes, but for more reliable conclusions. However, as Unit 3 at the Campbell Plant did not become operational until September 1980, it was necessary to alter the statistical design due to the resulting unbalanced nature [3 preoperational yr (1978-1980) and only 1 operational yr (1981)]. This complication was previously noted by Winnell and Jude (1981). The analysis of variance for each taxon was performed on $\log_{10}(x+1)$ transformed densities (Elliot 1971) by the University of Michigan's AMDAHL 470V/8 computer using BMD8V, a program of the BMD Statistical Software facility supported by the Statistical Research Laboratory at the University of Michigan.

The original design was structured such that there were five factors: Construction Time [before and after

discharging of heated effluent via offshore discharge structures began], Year [1978-1981], Region [treatment (inner) and reference (outer)], month [April, July, and October], and Depth [3 m, 6 m, 9 m, 12 m, and 15 m]. All factors were fixed factors, except Year, which was random and nested within Construction Time. Because the Construction Time factor was no longer a balanced factor, thereby complicating computation and interpretation of results, it was necessary to eliminate this factor and utilize the Year factor as an unnested factor. In order to do this, the design of the ANOVA was altered to a four-way mixed, factorial model where all factors were fixed, except Year, which remained random.

While determination of a plant effect was measured by the F-ratio of the mean square errors of the Construction Time x Region interaction and Year x Region interaction (MS_{CR}/MS_{YR}) in the original design, elimination of the Construction Time factor required utilization of a different test for plant effect. The test for plant effect that we employed in the new design was directly related to the degree of sensitivity of the ANOVA. The ANOVA's sensitivity to population changes was determined by R, the least detectable true ratio (see Cohen 1969; Johnston 1974; Winnell and Jude 1980):

$$R \geq 10^{2^{0.5}\delta} \quad \text{and} \quad R \leq 10^{-2^{0.5}\delta}$$

The quantity δ (least detectable true difference) in the R equation was determined by Johnston (1974) by re-expressing the formula of Sokal and Rohlf (1969):

$$\delta = s(2/n)^{0.5}\ \{t_{\alpha[\gamma]} + t_{2(1-P)[\gamma]}\}^2,$$

where;

δ = least detectable true difference,
s = true standard deviation,
γ = degrees of freedom,
n = number of observations,
t = Student's <u>t</u>,
α = significance level,
P = desired probability that a difference will be found to be significant.

Calculations of δ from Campbell ANOVAs assumed:

s = mean square error,
γ = infinity,
n = average number of observations per cell in the reduced ANOVA [the total number of observations/4 (see below)],
α = 0.05,
P = 0.95.

Reducing the number of ANOVA cells such that columns were years pooled into preoperational (1978-1980) and operational (1981) years, and rows were regions (inner, outer), there remained four cell means corresponding to those of Johnston (1974, p. 27).

Subsequent substitution of δ into the R equation permitted us to determine the minimum amount of change necessary to detect that a change had in fact occurred. This change corresponded to the sensitivity of the ANOVA, calculated at the 5% level of significance and with 95% certainty that a difference at least equivalent to δ would

be regarded as significant. Consequently, the least detectable true ratio expressed the minimum degree of change (either increase or decrease) which the inner region population density for a given animal must undergo relative to a similar estimate from the outer region in order to detect plant effect using the four-way mixed, factorial ANOVA. Therefore, the quantity R not only described the sensitivity of the ANOVA, but delimited the threshold below which, we can conclude, there was either no plant effect or the effect of plant operation did not exceed the ANOVA's level of sensitivity (see RESULTS AND DISCUSSION for detail).

To determine if the respective R values were exceeded by density changes observed at Campbell from 1978-1981, the four cell means from the reduced ANOVA were contrasted according to Johnston (1974):

$$R' = (IA+1/OA+1)/(IB+1/OB+1),$$

where;

R' = actual abundance change ratio,

IA = true mean number of animals m^{-2} (geometric mean) in the inner region after plant began operation,

OA = true mean number of animals m^{-2} (geometric mean) in the outer region after plant began operation,

IB = true mean number of animals m^{-2} (geometric mean) in the inner region before plant began operation,

OB = true mean number of animals m^{-2} (geometric mean) in the outer region before plant began operation,

Therefore, our test for plant effect on benthic populations as reflected in density fluctuations compared R' with R. If $R' \leq 10^{-2^{0.5}\delta}$ and $R' \geq 10^{2^{0.5}\delta}$, we were 95% certain the observed degree of change was significant at the 5% level, i.e., for a given animal, the inner region density relative to the outer region density significantly increased or decreased. This condition was judged to strongly indicate an effect due to discharge of heated effluent from plant operation.

Conversely, if $R' > 10^{-2^{0.5}\delta}$ and $R' < 10^{2^{0.5}\delta}$, we were 95% certain the observed degree of change was not significant at the 5% level of significance, i.e., for a given animal, the inner region density relative to the outer region density did not experience a significant increase or decrease in abundance. This condition could be judged as either no effect due to discharged heated effluent, or a non-detectable effect (see RESULTS AND DISCUSSION for detail).

ARTIFICIAL SUBSTRATE STUDY ON THE RIPRAP AREA

The riprap, comprised of large, irregular pieces of crushed limestone (0.5 to 2.0-m diameter), covers the intake and discharge structures. This protective cover extends from the shoreline to a depth of 11 m, ranges in width from 9-18 m, and has a total estimated area of 52,400 m^2 (Jude et al. 1982). Artificial substrates used to estimate both

benthic diversity and density on the riprap followed those utilized by Lauritsen (1979). As the geometric design of the artificial substrates was a truncated cone, area of individual substrates was calculated by:

$$A = p[r^2 + R^2 + (rR)s],$$

where;

A = area of a truncated cone,
p = 3.1416,
r = radius of circle at top of cone,
R = radius of circle at bottom of cone,
s = slant height of cone.

Each artificial substrate was constructed of quick drying concrete formed in paper cups, such that when dried, r = 26 mm, R = 36 mm, and s = 88 mm, with total area of each individual artificial substrate determined to be 0.02334 m^2.

Five artificial substrates were placed in each of five wire baskets. The contents of each basket were considered a replicate. The total area sampled per wire basket was equivalent to 5 times 0.02334 m^2 or 0.11668 m^2, assuming that 100% of each artificial substrate surface area was available to potential benthic colonizers. However, as positioning of the five artificial substrates relative to each other did not ensure that all available surface area was exposed to colonization, we followed the methodology of Lauritsen (1979) by assuming 10% of the area was unavailable to colonization due to posturing of substrate surface areas against themselves (0.11668 m^2 - 0.01167 m^2 = 0.010501

m^2). Therefore, the conversion factor used to convert the number of individuals per wire basket to number m^{-2} was 9.52.

Wire baskets containing the artificial substrates were lodged by divers in the riprap surrounding the intake structure on 15 July and were retrieved on 22 October. Scuba divers placed dislodged wire baskets immediately in 0.1-mm mesh bags, which were sealed and returned to the ship. On board ship, each bag and its contents were placed in separate 18.9-liter plastic buckets, preserved with 4% formaldehyde solution, and capped. Samples were returned to the GLRD Benthos Laboratory for sorting and identification procedures following those previously described for processing benthic samples collected by Ponar grabs.

MALACOSTRACANS ENTRAINED AND COLLECTED BY NET AND SLED TOWS

Malacostracans collected in net tows were sampled using a 0.5-m diameter, nylon plankton net of no. 2 mesh (363-micron aperture). A Rigosha flowmeter attached to the center opening of the plankton net was used to calculate volume of water sampled. When flowmeters were not available or stopped functioning, average flowmeter values were computed from readings available from the same stations at other times or from stations of comparable depth. When flowmeter readings were conspicuously different from other tows at the same station, averages of readings for the appropriate station and diel period were used. All meter

revolutions were converted to volume filtered using 1 revolution = 15 liters of water. Flowmeters were calibrated in a swimming pool by walking a measured distance with a flowmeter attached to a 0.5-m diameter hoop without the net (see Jude et al. 1979).

Net tow samples from the beach were collected at station R (in the vicinity of the intakes) in Lake Michigan (Table 1). Three people simultaneously hand-towed two nets for a distance of approximately 61 m once during the day and once at night. These tows were performed once per month during April and September and twice per month in May, June, July, and August during 1981.

At deeper stations, malacostracans were collected in horizontal, 5-min tows taken at discrete depths parallel to shore at six stations (I, J, L, N, O, W) in Lake Michigan (Table 1). Sampling was conducted during the day and night on the same schedule as beach samples. A total of 476 net tow samples were collected during 1981, with only the 7 May station R sample missing (0.5-m night net tow).

Net tows at depths less than 3 m were taken from outboard motorboats. The University of Michigan's R/V Mysis was used for tows at deeper stations. For each tow, the following procedure was implemented:

1) Plankton net (with attached 0.47-liter Mason jar) and depressor were lowered to desired depth (average ship speed was 3 to 6 km/h).

Table 1. Net and sled tow stations and respective sampling depths (m) at which malacostracans were collected during 1981 near the J.H. Campbell Plant, eastern Lake Michigan. The last row in the table denotes bottom depth at each station. Sled tow samples were collected on the bottom, while net tow samples were collected at all depths noted in the table, except at the bottom depth.

Station						
R	I	J	L	N	O	W
0.5	0.5	0.5	0.5	0.5	0.5	0.5
		2.5	2.0	2.5	3.0	4.5
			4.0	4.5	6.0	8.5
			5.5	6.5	9.0	11.5
				8.5	11.0	14.0
1.0	1.5	3.0	6.0	9.0	12.0	15.0

2) Plankton net was towed horizontally for 5 min when the desired depth was was attained. The amount of cable or rope needed to obtain the desired depth was calculated trigonometrically.

3) Plankton net was hauled to surface where contents were washed into the attached Mason jar using a water hose.

4) Contents of the Mason jar were preserved with 40 mL of buffered formaldehyde, labelled, and sealed.

Sled tows along the lake bottom were made with a benthic fish larvae sled equipped with a flowmeter (Yocum and Tesar 1980). A single 5-min sled tow was performed once during the day and once during the night at all Lake Michigan stations coincident with net tows as time and weather permitted. All sled tows were made from outboard motorboats. A total of 140 sled tow samples were collected during 1981.

Due to the design of the Unit 3 cooling system, entrainment samples were collected at the opening of the 5.5-m (18-ft) diameter intake pipe which enters the uncovered intake canal near the Lake Michigan shoreline. Collection at this point ensured that very few, if any, malacostracans occurring in the intake canal were sampled, which could potentially bias entrainment samples with malacostracans not originating from Lake Michigan.

Entrainment samples were collected from a raft situated directly above the juncture where the buried intake pipe carrying cooling water from Lake Michigan entered the on-land intake canal. A 0.5-m diameter plankton net, identical

to that used for field sampling (363-micron mesh), was lowered into a central position in the mouth of the intake pipe. An 18-kg weight was needed to keep the net at the desired depth. The amount of cable necessary to maintain this central position was calculated trigonometrically. Location of the raft and amount of cable necessary to ensure correct positioning of the net in the opening was verified by scuba diver observations.

Four replicate samples were collected four times during each 24-h period sampled (day, dawn, dusk, and night). Each replicate consisted of a 10-min sample. Sampling was performed on a weekly basis from May through September, three times per month in April and October, and twice per month from January through March and November through December 1981. The periods of dawn and dusk were defined as the period extending from 1 h before to 1 h after both sunrise and sunset as determined from the Nautical Almanac Office (1981), United States Naval Observatory, Washington D.C. During 1981, a total of 590 entrainment samples was collected, with only the four entrainment samples from 10 July missing. However, as the accuracy of entrainment sample flowmeter readings of <500 revolutions (<7.5 m^3 filtered) was suspected to be low due to fouling or malfunction, 48 of the 590 entrainment samples collected were considered unreliable and were not included in the dataset.

All samples were returned to the GLRD Fishery Laboratory where malacostracans (Amphipoda, Mysidacea, and Isopoda) were removed from each sample and stored in 4- or 8-mL vials. For samples having excessively large numbers of amphipods or mysids, the first 50 individuals of each taxon were removed, with the remainder enumerated to provide the total number in the sample from which an appropriate conversion factor was derived. At this stage in processing malacostracans, samples were entrusted to the Benthos Laboratory for identification and measurement.

Malacostracans were identified to the lowest practical taxonomic level. For each specimen, body length was measured to the nearest 0.1 mm: for amphipods, from the insertion point of the first antenna on the head to the tip of the telson; for mysids, from the tip of the rostrum to the posterior extension of the telson; and for asellids, from the anterior portion of the head to the tip of the uropods. In addition, head length was determined for numerous, but not all, specimens. Reproductive status determined for all specimens was straightforward (juvenile, gravid female, spent female, and male), except for *Mysis relicta*, which followed the method of McWilliam (1970).

Malacostracans were sorted, identified, assigned a reproductive status, measured, and grouped into 0.5-mm size categories. These data along with appropriate station information (e.g., depth, time, water temperature), were entered directly onto an internal computer datafile of the

Michigan Interactive Data Analysis System (MIDAS) at the University of Michigan Computing Center. With the aid of data analysis routines of MIDAS, appropriate statistics were generated for malacostracans occurring in net tows, sled tows, and entrainment samples.

Because net tow sampling involved sequential vertical subsamples of depth at each station, density and meter revolutions for each subsample were corrected to account for any contamination from individuals occurring at other depths through which the net had to be hauled when retrieved and to provide a more accurate measure of the number of cubic meters of water passing through the net. The adjustment procedure for organisms captured in all tows other than surface tows is outlined in detail in Figure 6 of Jude et al. (1982). The method consisted of sequential subtraction of numbers of malacostracans from the lower water depth levels based upon densities observed in upper water strata. It was assumed that malacostracans were homogeneously distributed within a water stratum and that nets passing through a particular stratum from a lower level would catch individuals in proportion to the volume of water filtered. Organisms from all tows conducted below the surface stratum, which were probably caught during the vertical haul following termination of the horizontal tow, were removed via calculation from the final total malacostracan densities. It was assumed that any contamination incurred while lowering the net was negligible. The effect of

differential vertical distribution due to size was mitigated by stratifying malacostracans from each sample into 0.5-mm length intervals.

Biomass estimates for *Pontoporeia hoyi* and *Gammarus* spp. were generated by summing the products of the weights for mid-point lengths for each successive 0.5-mm size class times the number of individuals occurring in each respective size class. The length-weight curve (ash-free dry weight in mg) used for *P. hoyi* and *Gammarus* spp. was developed by Johnson and Brinkhurst (1971) for Lake Ontario specimens:

$$\textit{P. hoyi}\ \mathrm{wt(mg)} = 0.014L^{2.550},$$

$$\textit{Gammarus fasciatus}\ \mathrm{wt(mg)} = 0.014L^{2.444}.$$

Similar biomass estimates determined for *Mysis relicta* were made utilizing the length-weight curve (dry weight) of Morgan (1976):

$$\textit{Mysis relicta}\ \mathrm{wt(mg)} = 0.00016L^{3.94}.$$

Biomass was not estimated for remaining taxa.

As previously noted, pumping operations at Unit 3 draw cooling water from a depth of 11 m (1.1 km offshore) in Lake Michigan. In the process, many types of animals are entrained, many of which are malacostracans. In an attempt to evaluate the effect of entrainment on populations of malacostracans in the lake, we assumed the area of greatest potential impact was a 2-km^2 area encompassing the 3 to 18-m

depth regime. This area is equivalent to 4×10^6 m^2. The volume of water (V) overlying the area with these dimensions is 4.2×10^7 m^3 [$V_{total} = V_{rectangle} + V_{prism} = (3\ m)(2{,}000\ m)^2 + 0.5(15\ m)(2{,}000\ m)^2$]. Both area and volume estimates were assumed to be constant during any given time period. In addition to these, we calculated an average daily pumping rate for Unit 3 based on data supplied by Campbell Plant personnel for several different time periods of interest. The maximum daily pumping rate for Unit 3 is 1.766×10^6 m^3 day^{-1}, which we used to estimate maximal entrainment. However, the pumping rate which we assumed was the average actual daily pumping rate during any given day during 1981 was 1.115×10^6 m^3 day^{-1} (based on pumping data from January through December) and was used to estimate actual entrainment. Finally, when utilizing net tow densities for which estimates were limited to the April through September time period, we used net tow density averages from the 3 to 15-m stations only and the actual average daily pumping rate of 1.177×10^6 m^3 day^{-1}. Using these assumptions in conjunction with measured densities at specified time periods, we were able to evaluate the effect of entrainment on lake abundances of certain malacostracans using the following equations:

1) Total average number of P. hoyi or M. relicta present in the 2-km^2 area in the 3 to 18-m depth regime at any average, given time during the year

P. hoyi = $[4 \times 10^6\ m^3][3{,}849\ m^{-2}$ (Inner region density at 3 to 15 m, 1981)]

$= 1.54 \times 10^{10}\ m^3$.

M. relicta = $[4 \times 10^6\ m^3][188\ m^{-2}$ (Morgan and Beeton 1978)]

$= 7.52 \times 10^8$.

2) Annual entrainment based on January-December average entrainment for each taxon

Maximum number entrained annually = (no. entr. m^3) (1.766×10^6 m^3 $days^{-1}$) (365 day yr^{-1}).

Actual number entrained annually = (no. entr. m^3) (1.115×10^6 m^3 m^3 day^{-1}) (365 day yr^{-1}).

3) The percentage that the density of each taxon entrained represents of its respective benthic density in the 2-km^2 area

Maximum % = (max. no. entrained annually/ total no. in 2-km^2 area)(100).

Actual % = (actual no. entrained annually/ total no. in 2-km^2 area)(100).

4) The percentage that the density of *P. hoyi* and *M. relicta* (April-September) represents of their respective average daily pelagic densities in the volume of water overlying the 2-km^2 area

Maximum daily % (*P. hoyi*) =

$[(1.766 \times 10^6\ m^3\ day^{-1})(2.347\ m^{-3})/$

$(4.2 \times 10^7\ m^3)(1.098\ m^{-3})](100)$

= 8.99%.

Maximum daily % (*M. relicta*) =

$[(1.766 \times 10^6\ m^3\ day^{-1})(0.1012\ m^{-3})/$

$(4.2 \times 10^7\ m^3\ day^{-1})(0.0569\ m^{-3})](100)$

= 7.48%.

Actual daily % (*P. hoyi*) =

$[(1.177 \times 10^6\ m^3\ day^{-1})(2.347\ m^{-3})/$

$(4.2 \times 10^7\ m^3\ day^{-1})(1.098\ m^{-3})](100)$

= 5.99%.

Actual daily % (*M. relicta* =

$[(1.177 \times 10^6\ m^3\ day^{-1})(0.1012\ m^{-3})/$

$(4.2 \times 10^7\ m^3\ day^{-1})(0.0569\ m^{-3})](100)$

= 4.98%.

5) The percentage that densities of pelagic _P. hoyi_ represent of densities of benthic _P. hoyi_ in the 2-km^2 area at any average time during April through September

$$\% \text{ pelagic} = [(4.2 \times 10^7 \text{ m}^3)(1.098 \text{ m}^{-3})/ 1.54 \times 10^{10}](100) = 0.299\%.$$

Maximum and actual biomass of malacostracans entrained on an annual basis was calculated in the same manner as was done for malacostracans entrained annually, except the average number of mg m^{-3} was substituted into the equation in place of no. m^2. For _P. hoyi_, this quantity was 1.272 mg m^{-3}; for mysids, 0.0296 mg m^{-3}; and for _Gammarus_ spp., 0.0788 mg m^{-3}. In the case of _P. hoyi_, accurate benthic abundances for individuals occurring in the size categories < 3 mm, 3 to 5 mm, 5 to 7 mm, and ≥7 mm were known from Ponar grabs collected at 3 to 15 m in the inner region during April, July, and October 1981. Based on the 1981 inner region benthic abundance of _P. hoyi_ in each size category and the weight (calculated from Johnston and Brinkhurst 1971) of an individual at the mid-point of each size class (i.e., 2 mm, 4 mm, 6 mm, and 8 mm), average benthic biomass was 1,541.9 mg m^{-2}. Therefore, the biomass of the benthic _P. hoyi_ population at any average, given time during the year was equivalent to $(4 \times 10^6 \text{ m}^2)$ (1,541.9 mg m^{-2}) = 6.168×10^9 mg = 6168 kg. Therefore, the percentage

that the biomass of entrained *P. hoyi* comprised of the benthic biomass is given by:

Maximum annual % = (Maximum annual biomass of entrained *P. hoyi*/6,168 kg)(100).

Actual annual % = (Actual annual biomass of entrained *P. hoyi*/6,168 kg)(100).

Estimating the effect of entrainment on *Gammarus* spp. was limited to October as benthic abundance on the riprap was representative of October only. The product of the average *Gammarus* spp. abundance from artificial substrates (139 m^{-2}) and the area of the riprap (52,400 m^2) represented the estimated total benthic *Gammarus* spp. density available to entrainment (7.284×10^6 individuals). As the October entrainment density of *Gammarus* spp. at the 3- to 15-m stations was 0.2005 m^{-3}, percent entrained was determined such that;

$$\text{Maximum daily \% entrained} = [(1.766 \times 10^6\ m^3\ day^{-1})(0.2005\ m^{-3})/7.284 \times 10^6](100) = 4.86\%.$$

$$\text{Actual daily \% entrained} = [(0.948 \times 10^6\ m^3\ day^{-1})(0.2005\ m^{-3})/7.284 \times 10^6](100) = 2.61\%.$$

The above constitute the general, and in several cases, the specific equations used to estimate the impact of entrainment on malacostracans. Quantities generated from these equations appear in the section entitled "Impact of entrainment on malacostracans."

Finally, it should be noted that annual entrainment estimates from the Cook Plant have been calculated with the same methodology used at Campbell, which was based on average no. m^{-3} entrained times maximum pumping rate. The number of annually entrained P. hoyi and M. relicta was previously determined to be 1.97×10^8 yr^{-1} and 1.11×10^8 yr^{-1}, respectively, at the Cook Plant (unpublished data, GLRD), using a methodology wherein mean densities of entrained organisms are calculated for two diel periods (day and night) and then multiplied by the proportional amount of water pumped by the plant during day and night over the sampling interval. Monthly values were summed to estimate annual entrainment. For comparison with results of this study, we based the Cook calculation on average number m^{-3} entrained and the maximum pumping rate (3.259×10^9 m^3 yr^{-1}) at the Cook Plant. These quantities (annual entrainment estimates) were 1.46×10^8 yr^{-1} for P. hoyi and 8.05×10^7 yr^{-1} for M. relicta at the Cook Plant.

RESULTS AND DISCUSSION

LAKE MICHIGAN FIELD SURVEY

General Distributions of Benthos

The 10 major constituents of the macrobenthic community, accounting for 109 of 129 taxa (Table 2) and 99.6% of the average benthic density in the survey area from 1978-1981 (7,724 m^{-2}) (Table 3), were the Chironomidae (51 taxa), Naididae (19 taxa), *Pisidium* (14 taxa), Tubificidae (12 taxa), Gastropoda (6 taxa), Turbellaria (4 taxa), Enchytraeidae, *Pontoporeia hoyi*, and *Stylodrilus heringianus* (Table 4). When averaged from 1978-1981, chironomids were the most frequently collected of the 10 constituents, occurring in 94% of the samples; *P. hoyi* was the most numerous (2,726 m^{-2}) (Table 3). Other dominant major taxa were chironomids (1,661 m^{-2}), naidids (1,256 m^{-2}), and tubificids (949 m^{-2}). Expressed as a percentage of total benthos, distribution of dominant taxa among regions was similar when averaged from 1978-1981, with the possible exception of *P. hoyi* (Table 5). Average 4-yr abundance of *P. hoyi* in the inner region was 3,068 m^{-2} (42% of mean benthic abundance), while that in the outer region was 2,385 m^{-2} (29% of mean benthic abundance).

In 1981, greatest average annual abundance for many major taxa was observed in both regions. However, increased annual density in the inner region did not occur to the extent it did in the outer region. When comparing 1981 annual abundance (operational year) with that based on

Table 2. Benthic macroinvertebrates identified from Ponar grabs collected from 1977-1981 and from net tows, sled tows, entrainment samples, and artificial substrates collected during 1981 near the J.H. Campbell Plant, eastern Lake Michigan.

Taxon
Cnidaria
Hydrozoa
Hydroida
Hydridae
Hydra sp.
Platyhelminthes
Turbellaria (spp. 1-4)
Annelida
Oligochaeta
Prosopora
Lumbriculidae
Stylodrilus heringianus
Plesiopora
Enchytraeidae (spp.)
Naididae
Amphichaeta leydigii
Arcteonais lomondi
Chaetogaster diaphanus
Chaetogaster diastrophus
Chaetogaster setosus
Dero digitata
Dero pectinata
Nais barbata
Nais behningi
Nais communis
Nais elinguis
Nais pardalis
Nais simplex
Nais variabilis
Piguetiella michiganensis
Pristina foreli
Pristina osborni
Stylaria lacustris
Uncinais uncinata
Vejdovskyella intermedia
Tubificidae
Aulodrilus limnobius
Aulodrilus pigueti
Limnodrilus angustipenis
Limnodrilus claparedeianus
Limnodrilus hoffmeisteri

Table 2. Continued.

Taxon
Limnodrilus profundicola
Limnodrilus spiralis
Limnodrilus udekemianus
Peloscolex freyi
Peloscolex multisetosus longidentus
Peloscolex superioriensis
Potamothrix moldaviensis
Potamothrix vejdovskyi
Rhyacodrilus coccineus
Hirudinea
Rhynchobdellida
Glossiphoniidae
Helobdella stagnalis
Mollusca
Gastropoda
Mesogastropoda
Hydrobiidae
Amnicola limosa
Bithinia tentaculata
Somatogyrus sp.
Valvatidae
Valvata sincera
Basommatophora
Lymnaeidae
Lymnaea sp.
Physella sp.
Eulamellibranchia
Sphaeriidae
Musculium transversum
Pisidium adamsi
Pisidium casertanum
Pisidium compressum
Pisidium conventus
Pisidium fallax
Pisidium ferrugineum
Pisidium henslowanum
Pisidium idahoense
Pisidium lilljeborgi
Pisidium milium
Pisidium nitidum f. *nitidum*
Pisidium nitidum f. *pauperculum*
Pisidium subtruncatum

Table 2. Continued.

Taxon
Pisidium supinum
Pisidium variabile
Pisidium walkeri
Sphaerium nitidum
Sphaerium rhomboideum
Sphaerium striatinum
Arthropoda
Arachnida
Acarina (spp.)
Crustacea
Amphipoda
Gammaridae
Gammarus fasciatus
Gammarus pseudolimnaeus
Crangonyx pseudogracilis
Haustoriidae
Pontoporeia hoyi
Talitridae
Hyalella azteca
Mysidacea
Mysidae
Mysis relicta
Isopoda
Asellidae
Asellus sp.
Insecta
Diptera
Chironomidae
Chironominae
Chironomini
Chironomus anthracinus-gr.
Chironomus fluviatilis-gr.
Chironomus halophilus-gr.
Cladopelma sp.
Cryptochironomus sp.1
Cryptochironomus sp.2
Cryptochironomus sp.3
Cryptochironomus cf. *rolli*
nr. *Cyphomella* sp.
Endochironomus sp.
Glyptotendipes (*Phytotendipes*) sp.
nr. *Harnischia* sp.
Microtendipes sp.
Parachironomus cf. *abortivus*
Parachironomus sp.1

Table 2. Continued.

Taxon
Paracladopelma cf. *nereis*
Paracladopelma cf. *undine*
Paracladopelma cf. *winnelli*
Paratendipes sp.
Phaenopsectra sp.
Polypedilum cf. *halterale*
Polypedilum cf. *illinoense*
Polypedilum cf. *scalaenum*
Polypedilum cf. *simulans*/*digitifer*
Polypedilum cf. *tuberculum*
Polypedilum sp.2
Robackia cf. *demeijerei*
Saetheria cf. *tylus*
Tanytarsini
Cladotanytarsus sp.
Micropsectra sp.
Paratanytarsus sp.
Rheotanytarsus sp.
Tanytarsus sp.
Orthocladiinae
Cricotopus (*C.*) *tremulus*-gr.
Cricotopus (*C.*) sp.
Cricotopus (*I.*) cf. *intersectus*
Cricotopus (*I.*) cf. *suspiciosus*-gr.
Cricotopus (*I.*) *sylvestris*-gr.
Cricotopus (*I.*) sp.
Heterotrissocladius cf. *changi*
Heterotrissocladius cf. *oliveri*
Hydrobaenus sp.
Nanocladius sp.
Orthocladius (*O.*) sp.
Orthocladius (*E.*) sp.
orthocladiini sp.2
Paracladius sp.
Parakiefferiella sp.
Psectrocladius cf. *simulans*
Thienemanniella sp.
Diamesinae
Monodiamesa cf. *tuberculata*
Potthastia cf. *longimanus*
Tanypodinae
Procladius sp.
Thienemannymia-gr.

Table 2. Continued.

Taxon
Ceratopogonidae
Ceratopogon sp.
Culicoides sp.
Probezzia sp.
Trichoptera
Molannidae
Molanna sp.
Leptoceridae
Nectopsyche sp.
Unidentifiable first instar larvae
Odonata
Coenagrionidae
Enallagma sp.
Hemiptera
Corixidae
Pleidae
Plea striola
Collembola

Table 3. Annual mean density (no. m^{-2}) and frequency of occurrence of major taxonomic groups in samples collected from 1978 to 1981 ($n = 180\ yr^{-1}$) near the J.H. Campbell Plant, eastern Lake Michigan.

Taxon	Mean density					Frequency of occurrence				
	1978	1979	1980	1981	1978-1981	1978	1979	1980	1981	1978-1981
Pontoporeia hoyi	1602	2883	2955	3466	2726	60.0	78.9	69.4	70.0	69.6
Gammarus fasciatus	0	0	0	1	<1	0.0	0.0	0.0	1.7	0.4
Mysis relicta	0	<1	0	1	<1	0.0	0.6	0.0	2.2	0.7
Asellus sp.	0	0	0	4	1	0.0	0.0	0.0	2.8	0.7
Chironomidae	2224	1204	1473	1743	1661	95.0	94.4	87.8	96.7	93.5
Oligochaeta	2213	2803	1619	3335	2492	78.3	79.4	74.4	78.9	77.6
Naididae	1128	1783	708	1408	1256	75.6	71.1	65.0	68.9	70.0
Tubificidae	886	735	627	1547	949	63.3	64.4	58.3	70.0	64.0
Enchytraeidae	68	189	125	128	128	16.7	42.8	33.9	40.6	33.5
Stylodrilus heringianus	131	96	159	252	159	18.9	14.4	19.4	19.4	18.1
Gastropoda	71	94	81	156	100	35.6	37.8	32.8	49.4	38.9
Pelecypoda	272	482	426	541	430	54.4	52.2	55.6	59.4	55.4
Pisidium	266	478	416	536	424	53.9	52.2	55.6	59.4	55.3
Other pelecypods	6	4	10	4	6	6.7	6.1	11.7	4.4	7.2
Hirudinea	4	2	5	3	3	5.0	2.2	5.0	3.9	4.0
Hydracarina	9	4	3	2	5	10.6	4.4	4.4	3.9	5.8
Hydra sp.	5	7	4	15	8	6.1	2.8	5.0	7.2	5.3
Turbellaria spp.	193	461	76	441	293	32.2	64.4	34.4	77.8	52.2
Other Insecta	<1	<1	6	5	3	0.6	0.6	7.2	5.0	3.3
Total benthos	6594	7940	6648	9715	7724	95.6	96.7	92.8	98.9	96.0

Table 4. Number of identifiably different taxonomic units collected within each of the major taxonomic groups occurring at 3 to 15 m in the inner and outer regions from 1978-1981. Samples were collected by Ponar grabs during April, July, and October of each year from eastern Lake Michigan near the J.H. Campbell Plant.

	3 m										
	Inner region					Outer region					Grand total
Taxon	1978	1979	1980	1981	Total	1978	1979	1980	1981	Total	
Chironomidae	14	12	14	13	22	10	6	13	14	23	30
Naididae	6	8	6	6	11	3	2	5	4	9	13
Tubificidae	0	0	0	0	0	0	0	0	0	0	0
<u>Pisidium</u>	0	0	1	0	1	0	0	0	0	0	1
Other pelecypods	0	0	0	0	0	0	0	0	0	0	0
Gastropoda	0	0	0	0	0	0	0	0	0	0	0
Other	2	2	2	4	7	1	3	5	7	9	10
Total	22	22	23	23	41	14	11	23	41	41	54
	6 m										
	Inner region					Outer region					Grand total
	1978	1979	1980	1981	Total	1978	1979	1980	1981	Total	
Chironomidae	14	15	11	17	27	15	13	15	17	23	30
Naididae	7	9	7	6	12	7	7	9	9	12	14
Tubificidae	1	3	3	3	7	3	0	1	1	6	7
<u>Pisidium</u>	2	0	1	2	3	2	2	1	3	4	5
Other pelecypods	0	0	0	0	0	0	0	0	0	0	0
Gastropoda	0	0	0	2	2	1	1	1	3	4	4
Other	4	3	4	7	8	2	5	4	7	8	9
Total	28	30	26	37	59	30	28	31	40	57	69

Table 4. Continued.

	9 m										
	Inner region					Outer region					
Taxon	1978	1979	1980	1981	Total	1978	1979	1980	1981	Total	Grand total
Chironomidae	21	18	17	24	32	19	20	18	20	27	33
Naididae	7	8	7	11	11	10	9	9	8	12	13
Tubificidae	5	6	4	6	8	5	6	5	7	8	9
Pisidium	8	6	4	3	10	7	7	3	6	9	11
Other pelecypods	1	0	0	0	1	1	0	0	1	2	2
Gastropoda	2	2	2	3	3	2	3	3	2	4	4
Other	6	4	7	12	14	5	5	7	6	9	14
Total	50	44	41	59	79	49	50	45	50	71	86

	12 m										
	Inner region					Outer region					
	1978	1979	1980	1981	Total	1978	1979	1980	1981	Total	Grand total
Chironomidae	18	18	17	17	24	22	19	17	21	30	31
Naididae	6	11	7	8	11	7	10	8	7	12	13
Tubificidae	5	6	5	5	9	7	5	7	6	8	9
Pisidium	9	8	8	7	11	8	9	8	8	9	12
Other pelecypods	0	2	1	0	2	1	1	1	1	1	2
Gastropoda	3	3	3	4	6	3	5	3	4	5	6
Other	5	4	5	9	12	5	6	5	8	12	15
Total	46	52	46	50	75	53	55	49	55	77	88

Table 4. Continued.

	15 m										
	Inner region					Outer region					
Taxon	1978	1979	1980	1981	Total	1978	1979	1980	1981	Total	Grand total
Chironomidae	15	17	16	15	23	15	20	15	17	24	26
Naididae	9	8	9	9	13	9	7	7	9	12	14
Tubificidae	5	6	6	7	8	7	7	4	7	10	11
Pisidium	8	8	9	8	9	9	11	9	9	11	11
Other pelecypods	1	2	1	1	2	2	3	1	1	4	4
Gastropoda	2	5	3	3	5	3	5	3	4	5	5
Other	6	6	6	11	11	8	8	5	11	13	14
Total	46	52	50	54	71	53	61	44	58	79	85

	All depths combined										
	Inner region					Outer region					
	1978	1979	1980	1981	Total	1978	1979	1980	1981	Total	Grand total
Chironomidae	26	26	26	29	42	25	24	27	31	41	51
Naididae	10	12	10	14	16	11	10	10	12	17	19
Tubificidae	7	9	7	8	10	9	8	7	9	12	12
Pisidium	12	11	9	8	12	9	11	9	9	12	14
Other pelecypods	1	2	1	1	2	2	3	1	2	4	4
Gastropoda	3	5	4	4	6	4	5	3	4	5	6
Other	7	7	9	16	18	7	10	9	16	18	23
Total	66	72	67	80	106	67	71	66	83	109	129

Table 5. Annual mean abundance (no. m^{-2}) and percentage of the total benthos each major taxonomic group comprised. Data were collected from 1978 through 1981 from the inner (treatment) and outer (reference) regions (n = 90 region^{-1} yr^{-1}) near the J.H. Campbell Plant, eastern Lake Michigan.

	Inner region									
	Mean density					Percentage of total benthos				
Taxon	1978	1979	1980	1981	1978-1981	1978	1979	1980	1981	1978-1981
Pontoporeia hoyi	1852	2930	3642	3849	3068	30	39	58	41	42
Gammarus fasciatus	0	0	0	3	<1	0	0	0	<1	<1
Mysis relicta	0	0	0	0	0	0	0	0	0	0
Asellus sp.	0	0	0	9	2	0	0	0	<1	<1
Chironomidae	2178	974	1048	1480	1420	35	13	17	16	19
Oligochaeta	1846	2895	1133	2951	2206	29	38	18	32	30
Naididae	929	2183	593	1614	1330	15	29	10	17	18
Tubificidae	772	549	415	1176	728	12	7	7	13	10
Enchytraeidae	59	129	71	71	83	<1	2	1	<1	1
Stylodrilus heringianus	86	34	54	90	66	1	<1	<1	1	<1
Gastropoda	63	81	72	170	96	1	1	1	2	1
Pisidium	232	403	300	539	368	4	5	5	6	5
Other pelecypods	3	3	9	7	6	<1	<1	<1	<1	<1
Hirudinea	2	0	5	2	2	<1	0	<1	<1	<1
Hydracarina	9	5	3	2	5	<1	<1	<1	<1	<1
Hydra sp.	3	14	2	7	7	<1	<1	<1	<1	<1
Turbellaria spp.	100	251	37	267	164	2	3	<1	3	2
Other Insecta	0	0	7	3	2	0	0	<1	<1	<1
Total benthos	6287	7556	6256	9289	7347	-	-	-	-	-

Table 5. Continued.

Taxon	Outer region									
	Mean density					Percentage of total benthos				
	1978	1979	1980	1981	1978-1981	1978	1979	1980	1981	1978-1981
Pontoporeia hoyi	1352	2837	2267	3083	2385	20	34	32	30	29
Gammarus fasciatus	0	0	0	0	0	0	0	0	0	0
Mysis relicta	0	1	0	3	1	0	<1	0	<1	<1
Asellus sp.	0	0	0	0	0	0	0	0	0	0
Chironomidae	2270	1433	1899	2006	1902	33	17	27	20	24
Oligochaeta	2580	2710	2106	3719	2779	37	33	30	37	34
Naididae	1326	1382	823	1202	1183	19	17	12	12	15
Tubificidae	1001	921	839	1918	1170	15	11	12	19	14
Enchytraeidae	77	250	181	184	173	1	3	3	2	2
Stylodrilus heringianus	176	157	263	414	253	3	2	4	4	3
Gastropoda	80	106	90	142	104	1	1	1	1	1
Pisidium	301	554	532	533	480	4	7	8	5	6
Other pelecypods	9	5	11	2	7	<1	<1	<1	<1	<1
Hirudinea	7	3	5	3	5	<1	<1	<1	<1	<1
Hydracarina	9	3	3	3	5	<1	<1	<1	<1	<1
Hydra sp.	7	0	7	24	9	<1	0	<1	<1	<1
Turbellaria spp.	286	671	116	615	422	4	8	2	6	5
Other Insecta	<1	<1	5	7	3	<1	<1	<1	<1	<1
Total benthos	6901	8324	7040	10140	8101	-	-	-	-	-

1978-1980 (preoperational years), percent increase for nearly all 10 major taxa was greater in the outer region than in the inner region. The most notable increases were those for tubificids, S. heringianus, and P. hoyi. Although all three taxa have displayed consistently greater densities in the outer when compared with the inner region during previous years, the former two taxa increased 108% and the latter 43% during 1981 when compared with 1978-1980. These increases were considerably more than concomitant increases of approximately 10 to 25% in the inner region when making the same comparison. Other representatives of the major taxonomic groups displayed rather similar regional changes or, as in the case of turbellarians, have exhibited very highly variable annual and regional population densities, which require interpretive caution. Overall, outer region density increased 37% during 1981 when compared with the previous 3-yr average, while that in the inner region increased only 10%. Nonetheless, density differences between 1981 and 1978-1980 were not unusual as annual abundances for all major taxa were quite variable, with 1979 and 1981 representing years of peak abundance. Subsequent evaluation of annual and regional trends will be discussed in the analysis of variance (ANOVA) section.

Determination of Plant Effect on Benthic Populations Due to Discharge of Heated Effluent

Basis of Interpretation--

A brief statement is in order to clarify interpretation of population changes (R') occurring below the limit of detection or sensitivity level of the ANOVA (R). Once stated, the R and R' parameters will be presented for subsequent taxa with the understanding that an interpretation similar to that ensuing below is intended, thereby greatly reducing excessive repetition.

The R value established the minimum level of detection at $\alpha = 0.05$ and $P = 0.95$ or sensitivity of the ANOVA. When estimated R' values were less than expected R values, density changes in the operational-regional populations were below the minimum detectable limit, thereby suggesting two possible interpretations (see METHODS). First, one could assume there was no plant effect. Second, there remains the possibility that there was a plant effect, but it was not detectable. While it is the second possibility that is of most concern, there is no statistical way with present datasets to distinguish between no effect and a non-detectable effect.

When the nature of the R values are examined, we feel that the R value not only provided a necessary delimiter on the ANOVA, but also assured that some quantitative change was detectable. By setting $\alpha = 0.05$ and $P = 0.95$, we were sure of low probabilities for Type I and Type II errors (Sokal and Rohlf 1969). By further restricting α and P, we

would have decreased the sensitivity of the ANOVA, i.e., increased the R value, and have been even more sure that excessive R' values would have been indicative of plant effect. Alternately, by relaxing α and P to lower levels, acceptance of a plant effect would have much greater potential for Type I and Type II errors. Consequently, any absolute density changes occurring below the limit of detection are regarded as having had minimal to no impact on the population. In conclusion, we feel R values generated at $\alpha = 0.05$ and $P = 0.95$ provided sufficiently reasonable assurance of detection of a true plant effect while limiting Type I and Type II errors, but can not provide absolute assurance in a system defined by probability statistics.

Pontoporeia hoyi--

Evaluation of heat effect on P. hoyi density was based on the population encountered at 9 to 15 m, as few or only sporadic occurrences were observed at depths less than 9 m (Fig. 2). Annual monthly abundances followed a similar pattern of lowest densities in April and highest in July (Fig. 3). A more detailed examination of density trends indicated that, although regional density trends were not generally widely disparate within a given depth, there was a high degree of variability associated with density of P. hoyi across depth, month, and year factors (Fig. 4, Appendix 1). This variability was expressed by the significance of higher-order interaction terms from the ANOVA (Table 6).

Of main effects in the P. hoyi ANOVA, all except region were significant. As was expected, temporal and depth-related density differences were evident. Regional density differences during each year favored higher numbers of P hoyi in the outer when compared with the inner region, consequently it was surprising that the regional main effect was not significant. Regardless of density differences noted by the ANOVA factors, density changes observed for P. hoyi at 9 to 15 m were below the level of detection of the ANOVA [R' = 1.22, R = 2.34 (Table 7)], indicating no measurable plant effect during the 1978-1981 time period.

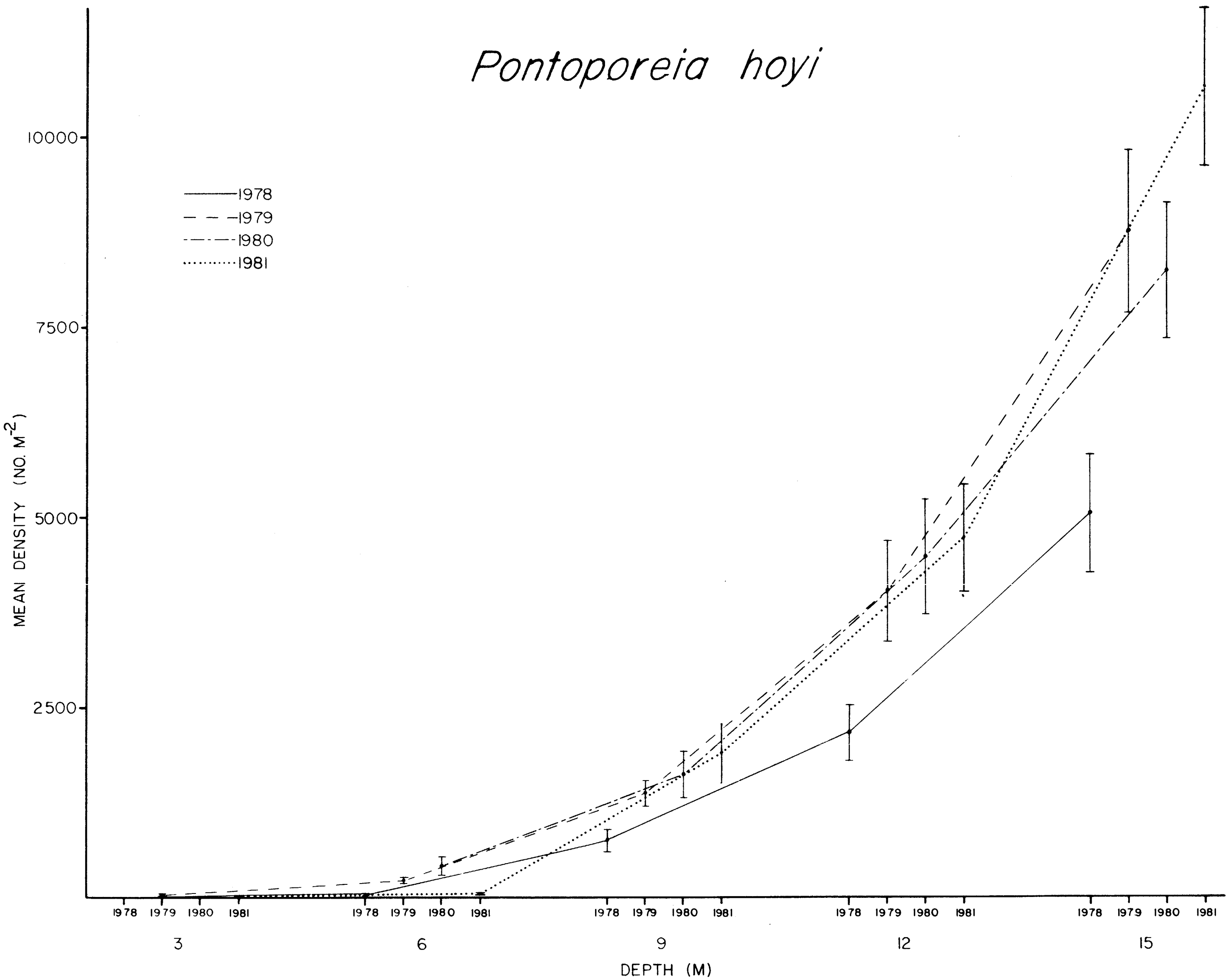


Fig. 2. Mean density (number m^{-2}) of P. hoyi collected at 3-15 m from 1978 through 1981 in eastern Lake Michigan near the J. H. Campbell Plant. Density estimates at each depth were computed by averaging over all months within each year (n = 36). Standard error denoted by vertical bar.

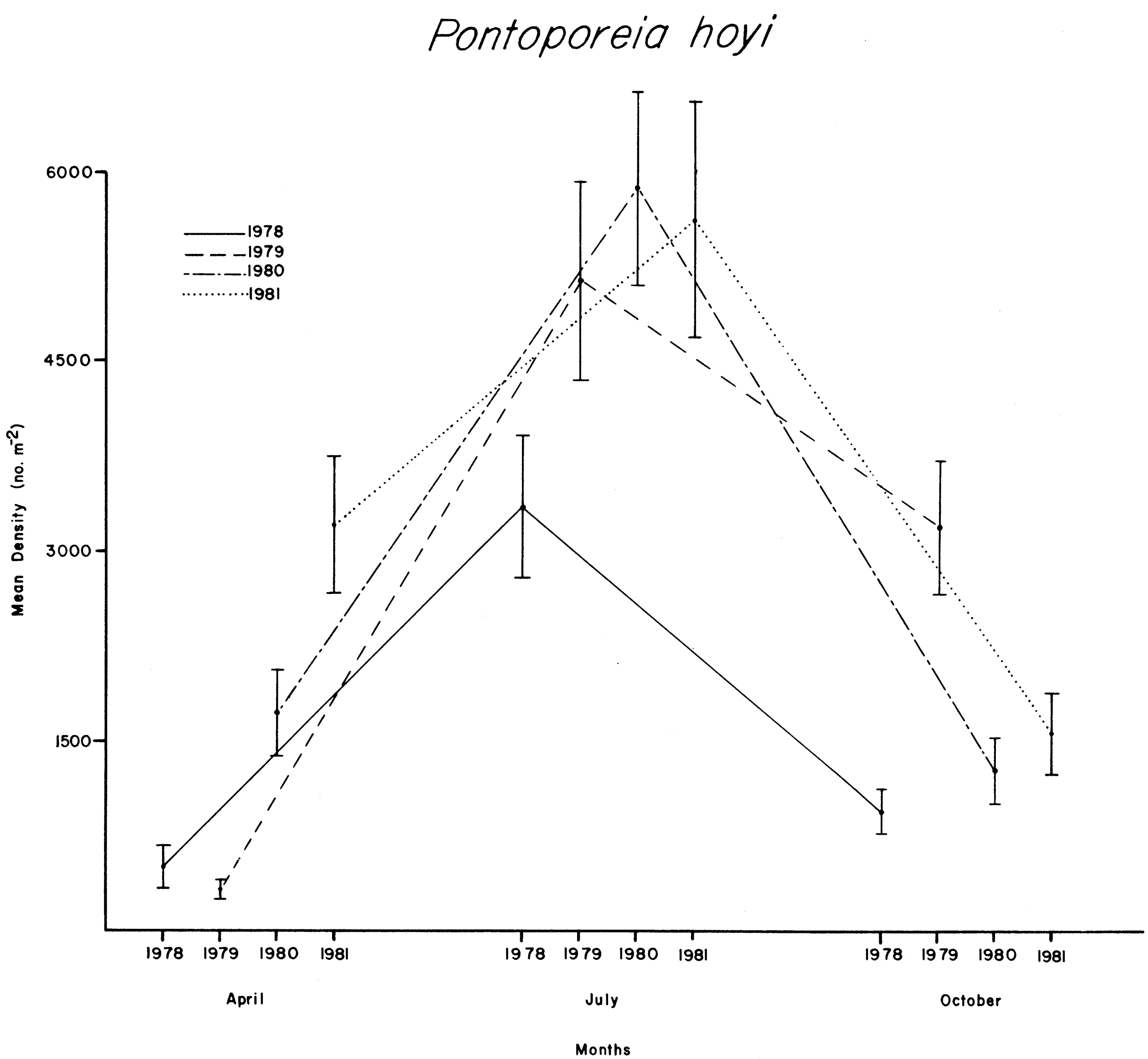


Fig. 3. Mean density (number m^{-2}) of P. hoyi collected during April, July, and October 1978 through 1981 in eastern Lake Michigan near the J. H. Campbell Plant. Density estimates for each month were computed by averaging over all depths within each year (n = 60). Standard error denoted by vertical bar.

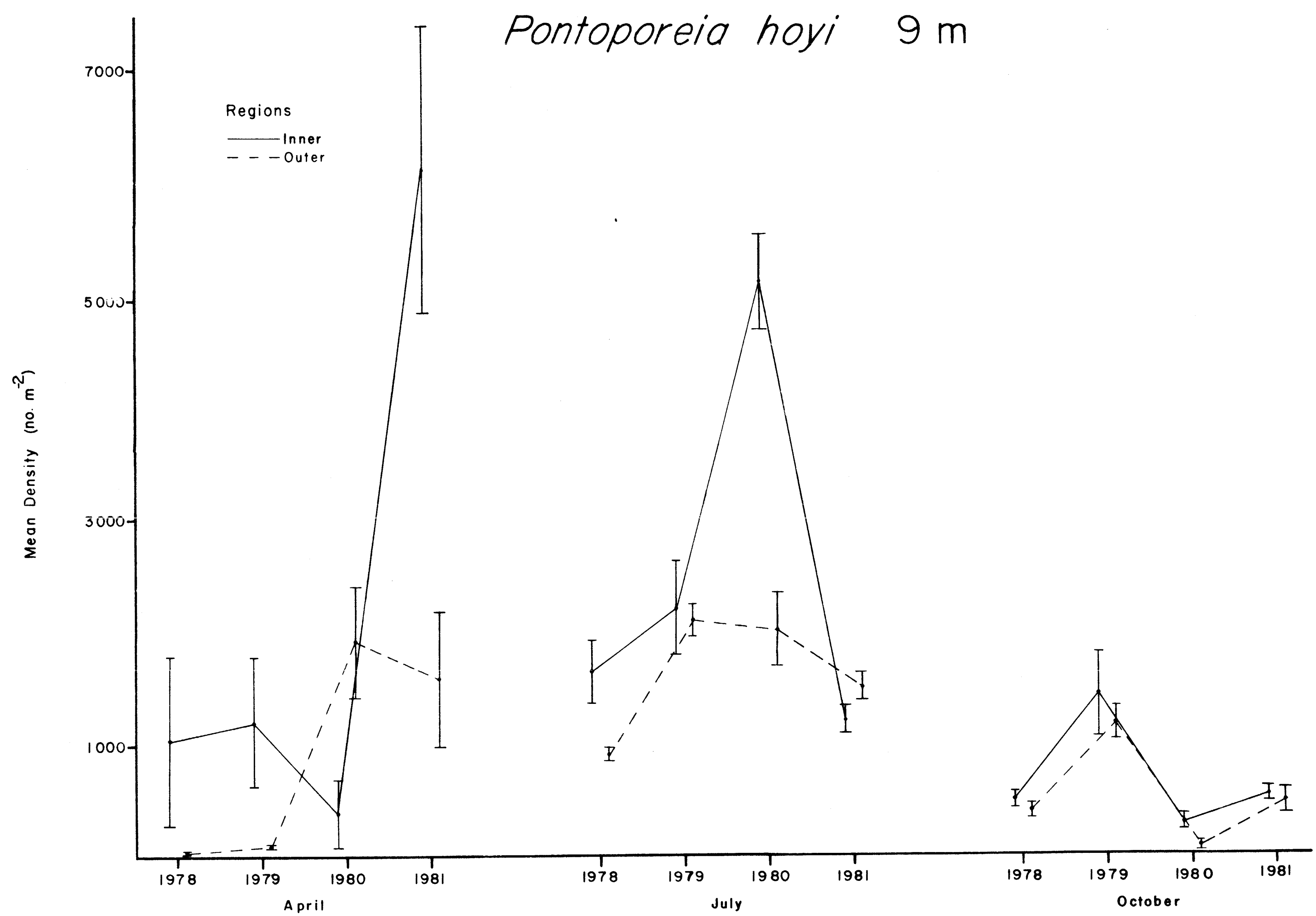


Fig. 4. Inner and outer regional mean densities (number m^{-2}) of P. hoyi collected in April, July, and October 1978 through 1981 from eastern Lake Michigan at 9-15 m near the J. H. Campbell Plant. Standard error denoted by vertical bar (n = 6). Inner region corresponds to treatment area near present thermal discharge. Outer region corresponds to reference area.

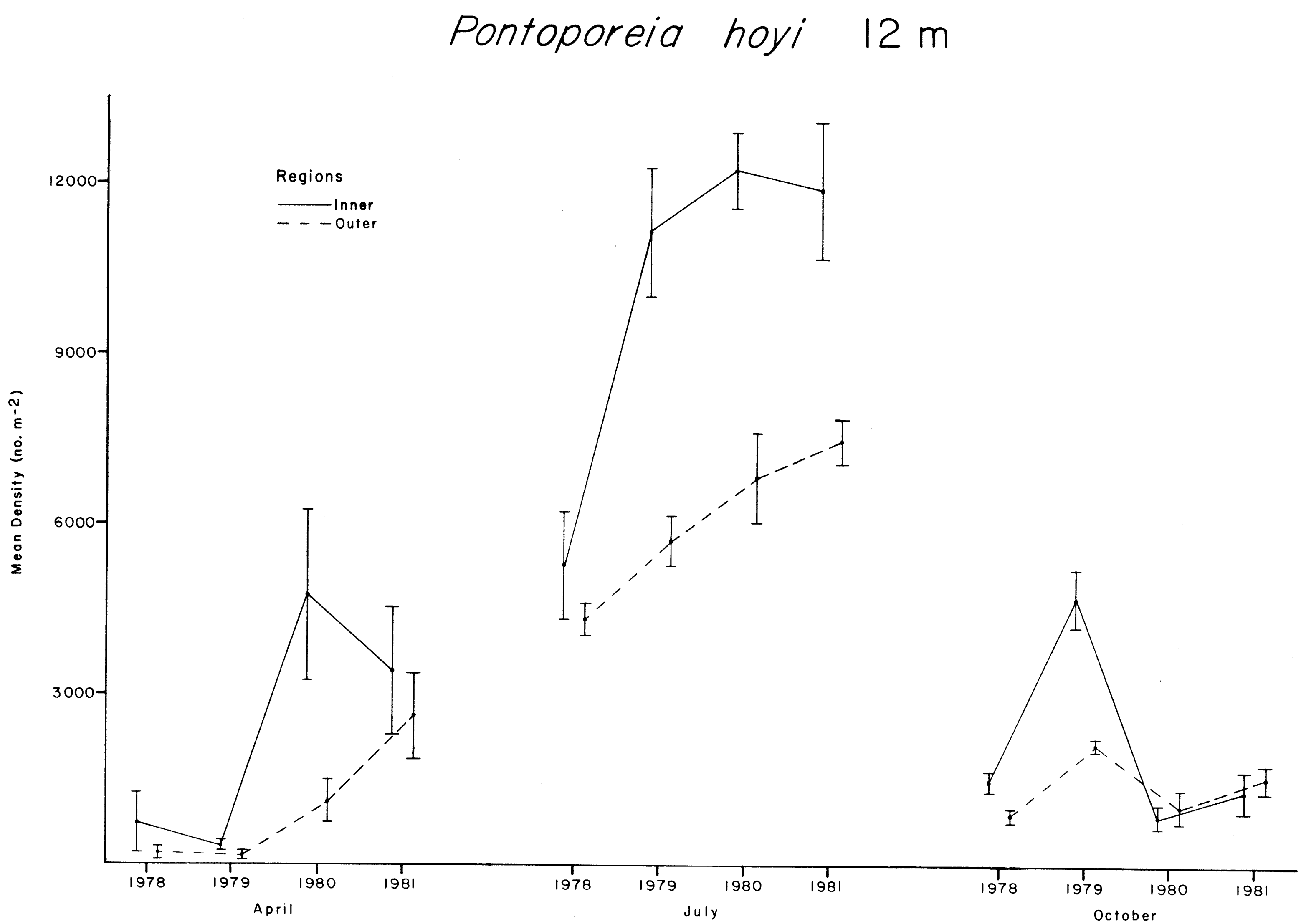


Fig. 4. Continued

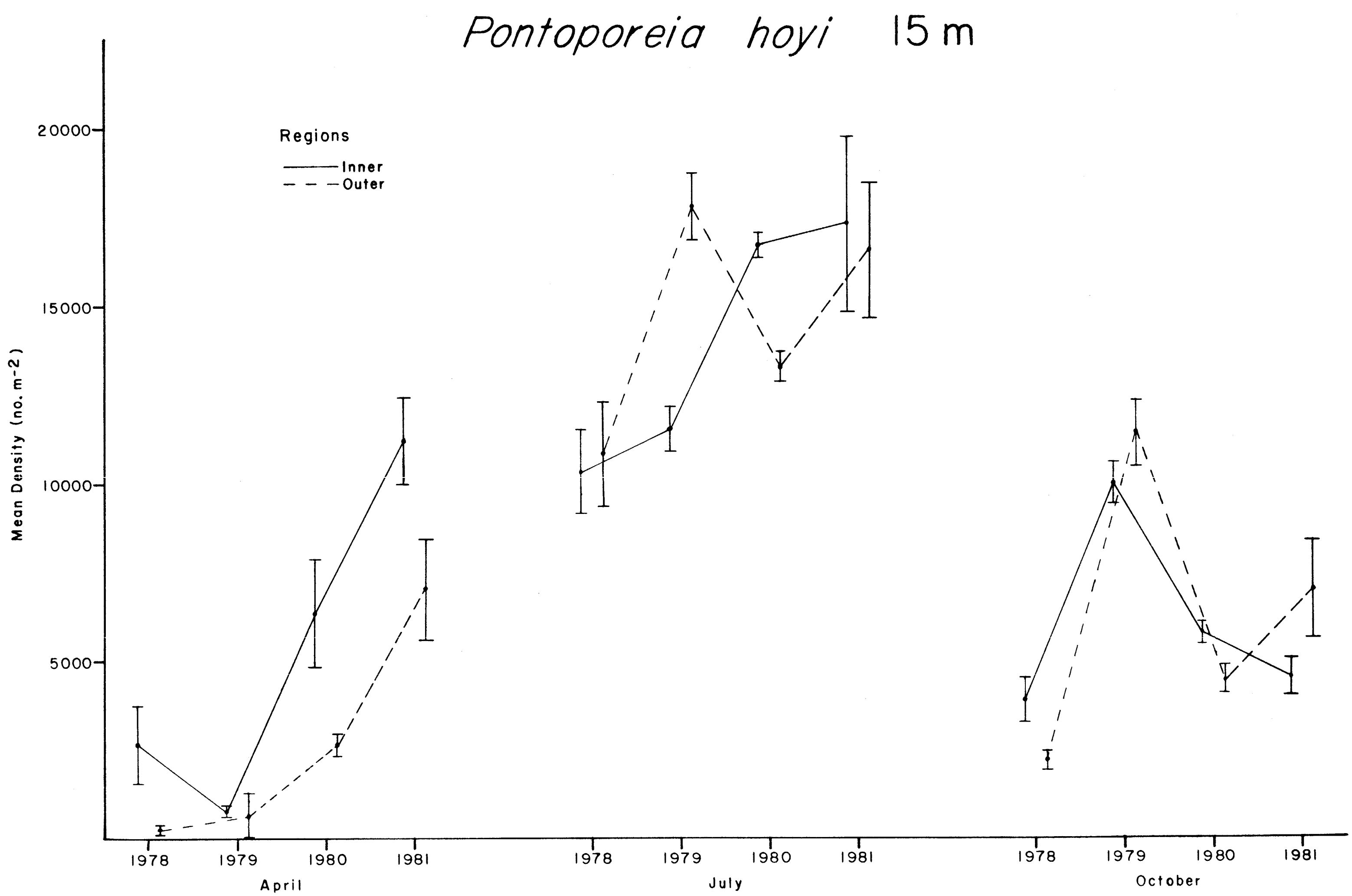


Fig. 4. Continued

Table 6. Analysis of variance results for densities [$\log_{10}(x+1)$] of <u>Pontoporeia</u> <u>hoyi</u> occurring at 9-15 m from 1978-1981 near the J.H. Campbell Plant, eastern Lake Michigan [NS = no significance ($p > 0.05$), * = $0.01 < p \leq 0.05$, ** = $0.001 < p \leq 0.01$, *** = $p \leq 0.001$].

Parameter	Sum of squares	Degrees of freedom	Mean square	F-ratio	Signif.
Region(R)	4.10	1	4.10	9.76	NS
Depth(D)	73.34	2	36.67	146.88	***
Month(M)	86.76	2	43.38	5.38	*
Year(Y)	26.63	3	8.88	31.71	***
RD	0.03	2	0.02	0.03	NS
RM	1.28	2	0.64	0.93	NS
DM	1.87	4	0.47	1.09	NS
RY	1.27	3	0.42	1.50	NS
DY	1.51	6	0.25	0.89	NS
MY	48.36	6	8.06	28.79	***
RDM	2.00	4	0.50	0.51	NS
RDY	3.65	6	0.61	2.18	*
RMY	4.12	6	0.69	2.46	*
DMY	5.21	12	0.43	1.54	NS
RDMY	11.85	12	0.99	3.54	***
Error	101.62	360	0.28		

Table 7. Regional averaged log densities for taxa before (1978-1980) and after (1981) operation of Unit 3 of the J.H. Campbell Plant, eastern Lake Michigan. Values of R' and R express the degree to which the inner region population density for a taxon would need to increase (upper limit) or decrease (lower limit) relative to a similar outer region estimate in order to be detected by the ANOVA at $\alpha = 0.05$ and $P = 0.95$ (see METHODS for detail).

Taxon	Averaged log densities				R′ values		R values	
	Inner		Outer		Limit		Limit	
	Before	After	Before	After	Upper	Lower	Upper	Lower
Pontoporeia hoyi	3.1929	3.5262	2.9770	3.3950	1.22	0.82	2.34	0.43
Chironomidae	2.6820	2.7767	2.8325	3.0622	1.37	0.73	1.74	0.57
Naididae	1.9681	1.9521	2.0605	2.1592	1.30	0.77	2.33	0.43
Tubificidae	2.5273	2.8751	2.8892	3.4253	1.54	0.65	2.98	0.34
Enchytraeidae	1.0126	1.1261	1.4049	1.9669	2.81	0.36	3.81	0.26
Stylodrilus heringianus	1.6065	2.3329	2.1644	2.9849	1.24	0.81	13.35	0.07
Gastropoda	1.1635	1.7274	1.4169	1.7293	1.78	0.56	4.46	0.22
Pisidium	2.1314	2.2559	2.2810	2.6770	1.87	0.54	3.07	0.33
Turbellaria	0.8804	1.7125	1.1946	2.1982	1.48	0.67	2.49	0.40
Total benthos	3.3405	3.5913	3.4670	3.8533	1.37	0.73	1.60	0.63

Chironomidae--

The average density of chironomids encountered during 1981 (1,743 m^{-2}) was very similar to the average abundance of the previous 3 preoperational yr (1,634 m^{-2}). Mean densities observed at each respective depth (Fig. 5) and during each respective month (Fig. 6) during 1981 did not differ from the previously observed range of values. Annual variability associated with depth and monthly mean densities was quite large. Outer region chironomid densities were slightly greater than those observed in the inner region at most depths, months, and years (Fig. 7, Appendix 2). However, based on the chironomid ANOVA, non-significance of the regional main effect indicated there was no regional density difference for the chironomids. Year, month, and depth main effects were significant (Table 8). The very high significance of higher-order interactions indicated the extreme variability associated with the predictive value of main effects variables on the chironomid population. These data supported the suspected case among chironomids that they are very mobile, transitory animals subject to a physically controlled environment in both larval and adult stages. Nevertheless, given density fluctuations observed, an R' value (1.37) less than the minimum detection limit (R = 1.74) (Table 7) indicated there was no detectable plant effect on the 3- to 15-m chironomid population during 1978-1981.

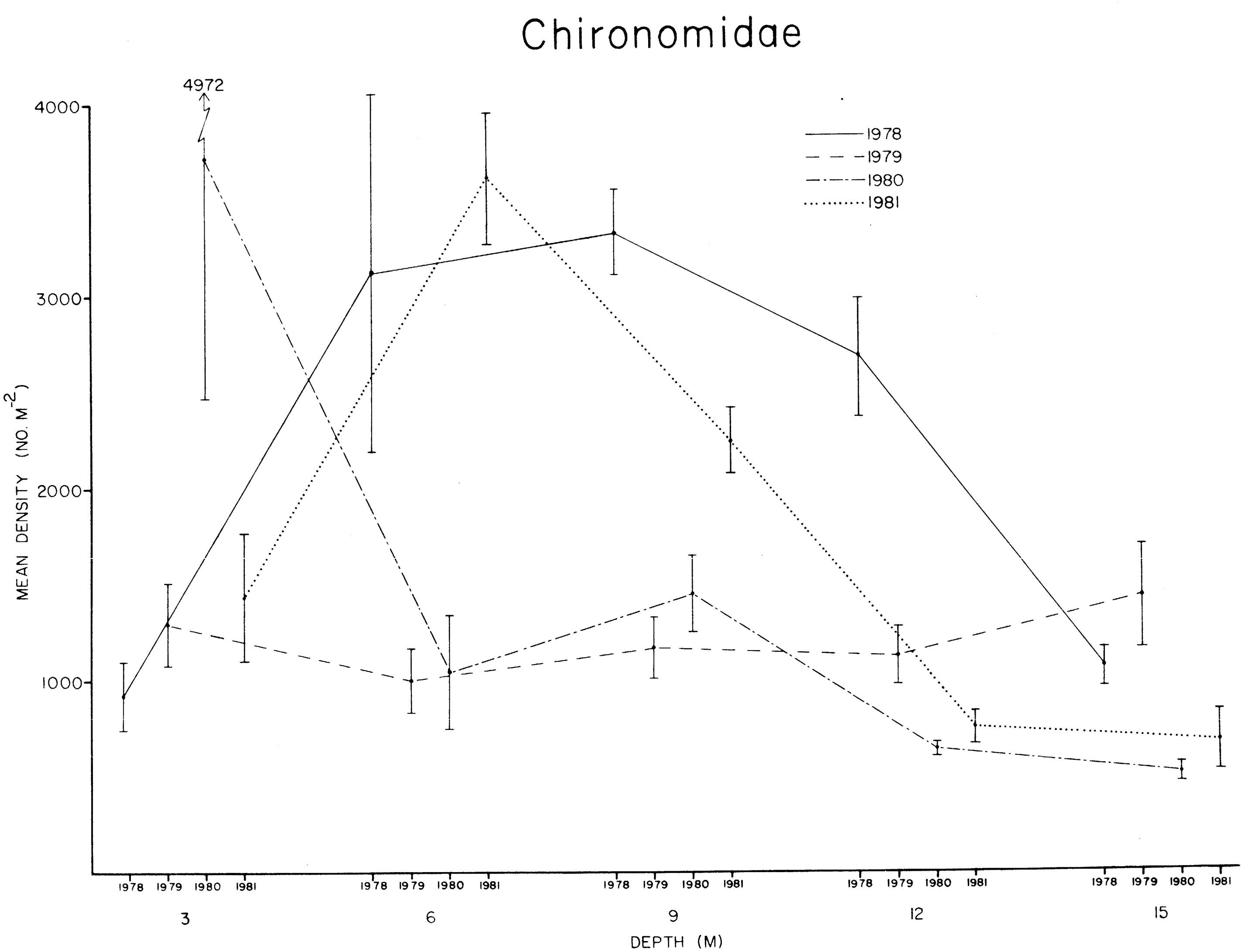


Fig. 5. Mean density (number m^{-2}) of chironomids collected at 3-15 m from 1978 through 1981 in eastern Lake Michigan near the J. H. Campbell Plant. Density estimates at each depth were computed by averaging over all months within each year (n = 36). Standard error denoted by vertical bar.

Chironomidae

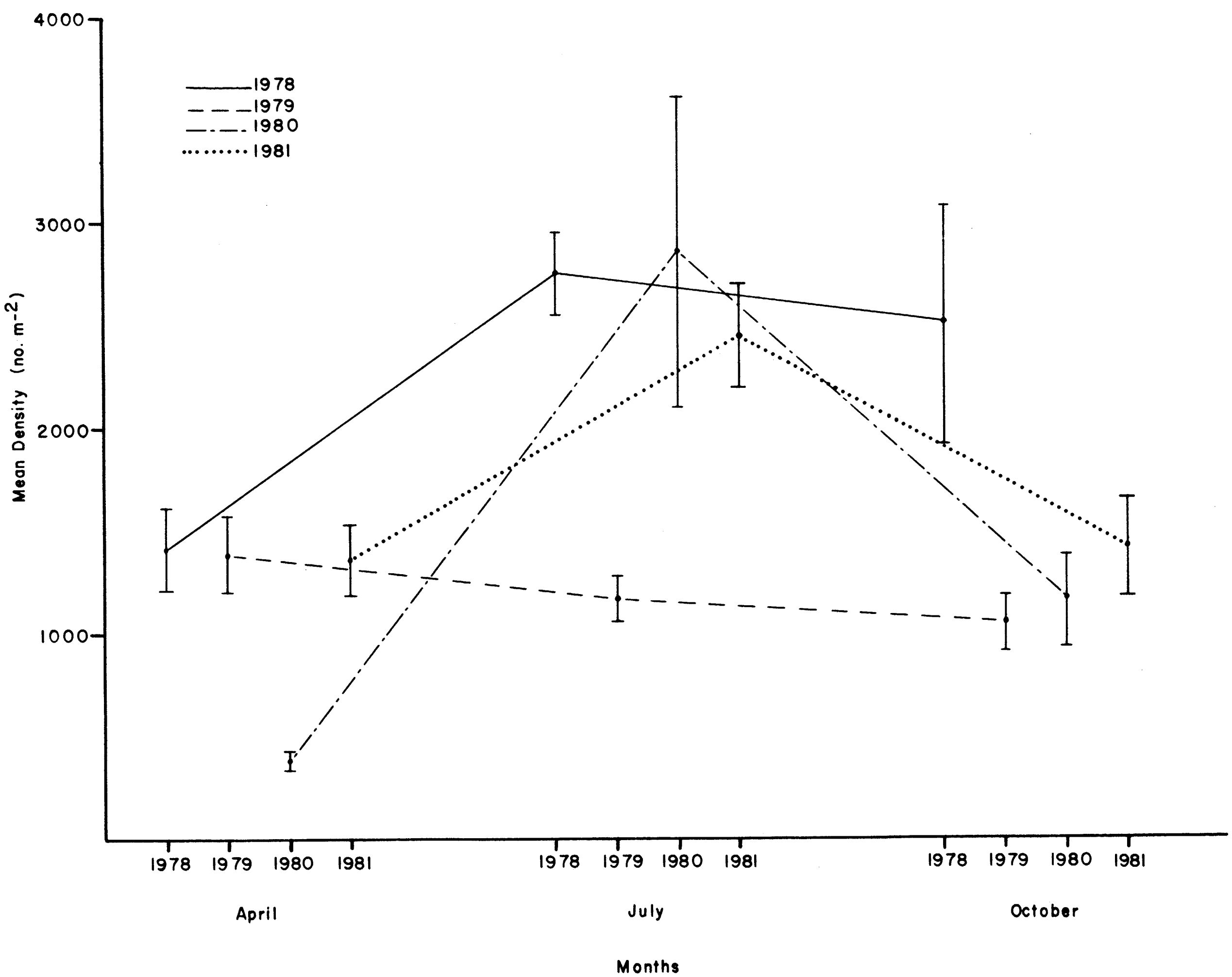


Fig. 6. Mean density (number m^{-2}) of chironomids collected during April, July, and October 1978 through 1981 in eastern Lake Michigan near the J. H. Campbell Plant. Density estimates for each month were computed by averaging over all depths within each year (n = 60). Standard error denoted by vertical bar.

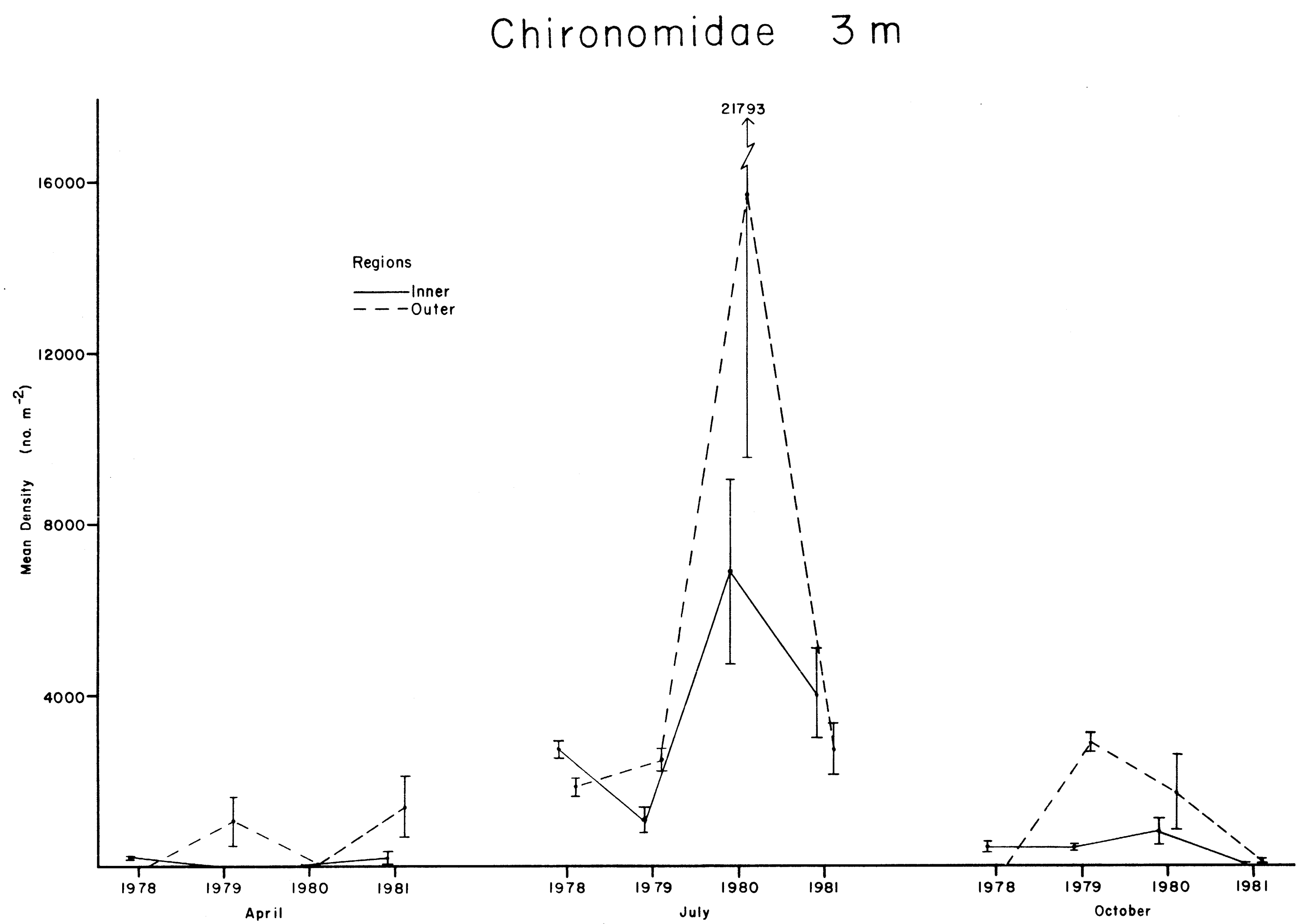


Fig. 7. Inner and outer regional mean densities (number m^{-2}) of chironomids collected in April, July, and October 1978 through 1981 from eastern Lake Michigan at 3-15 m near the J. H. Campbell Plant. Standard error denoted by vertical bar (n = 6). Inner region corresponds to treatment area near present thermal discharge. Outer region corresponds to reference area.

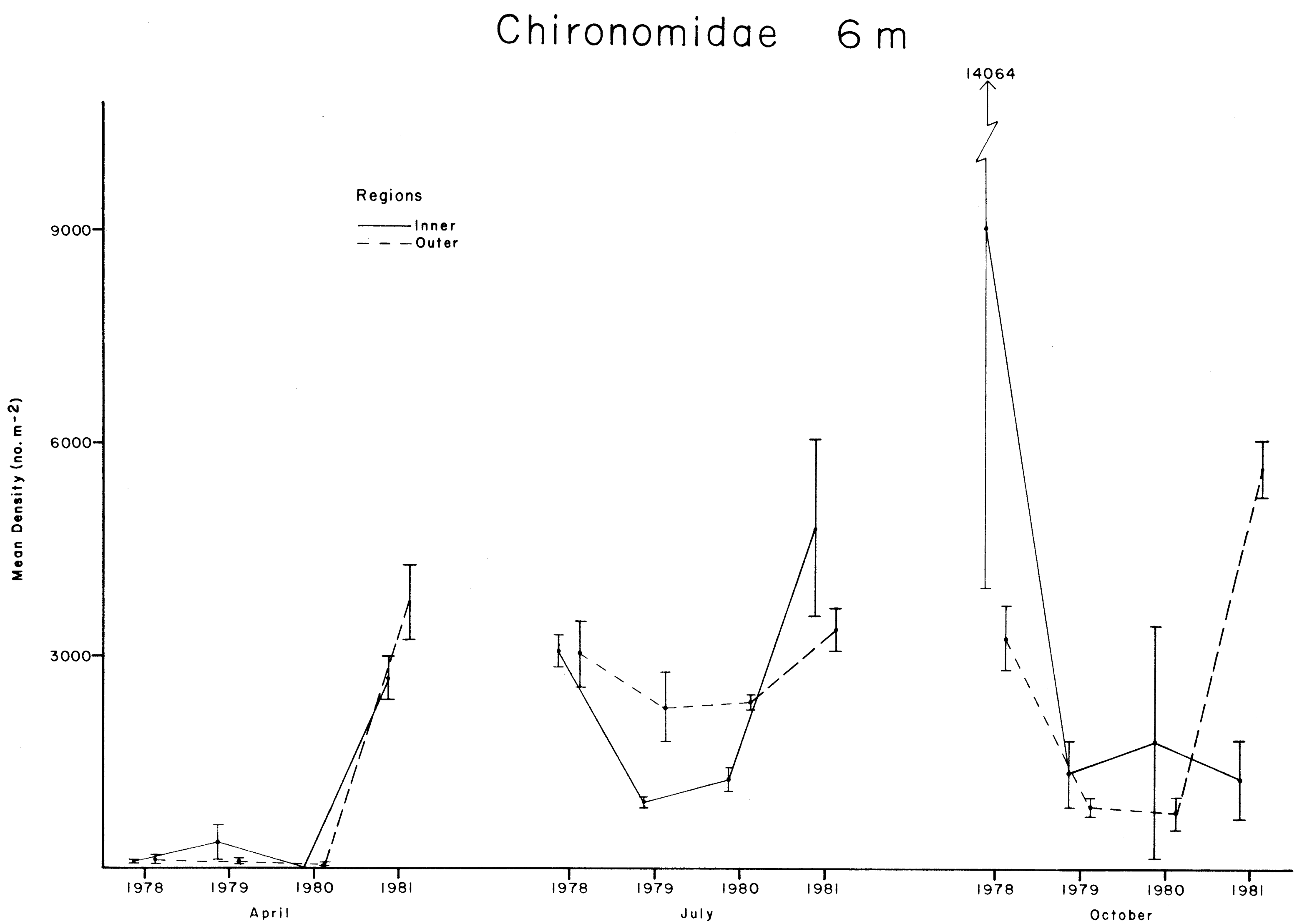
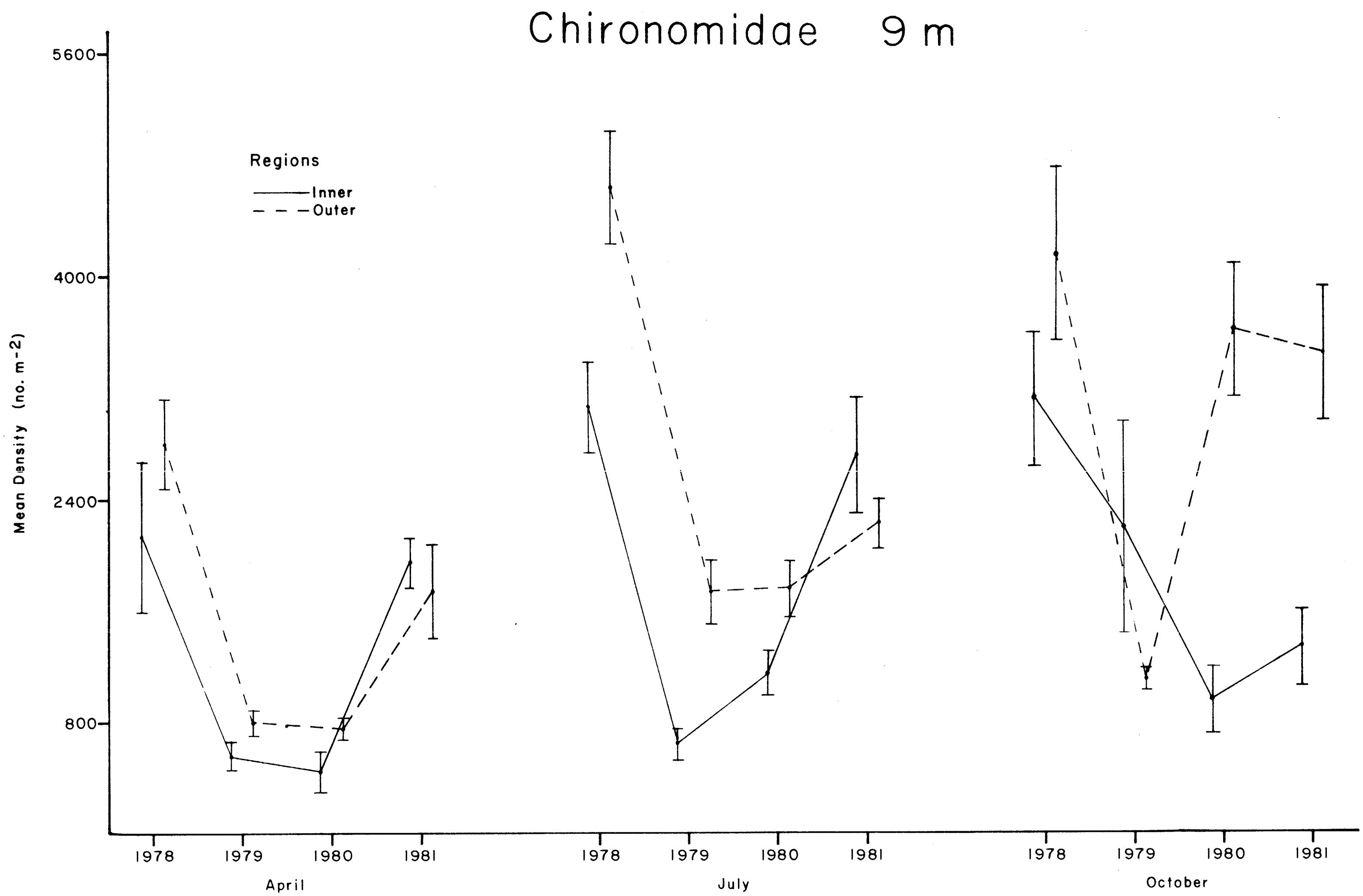


Fig. 7. Continued



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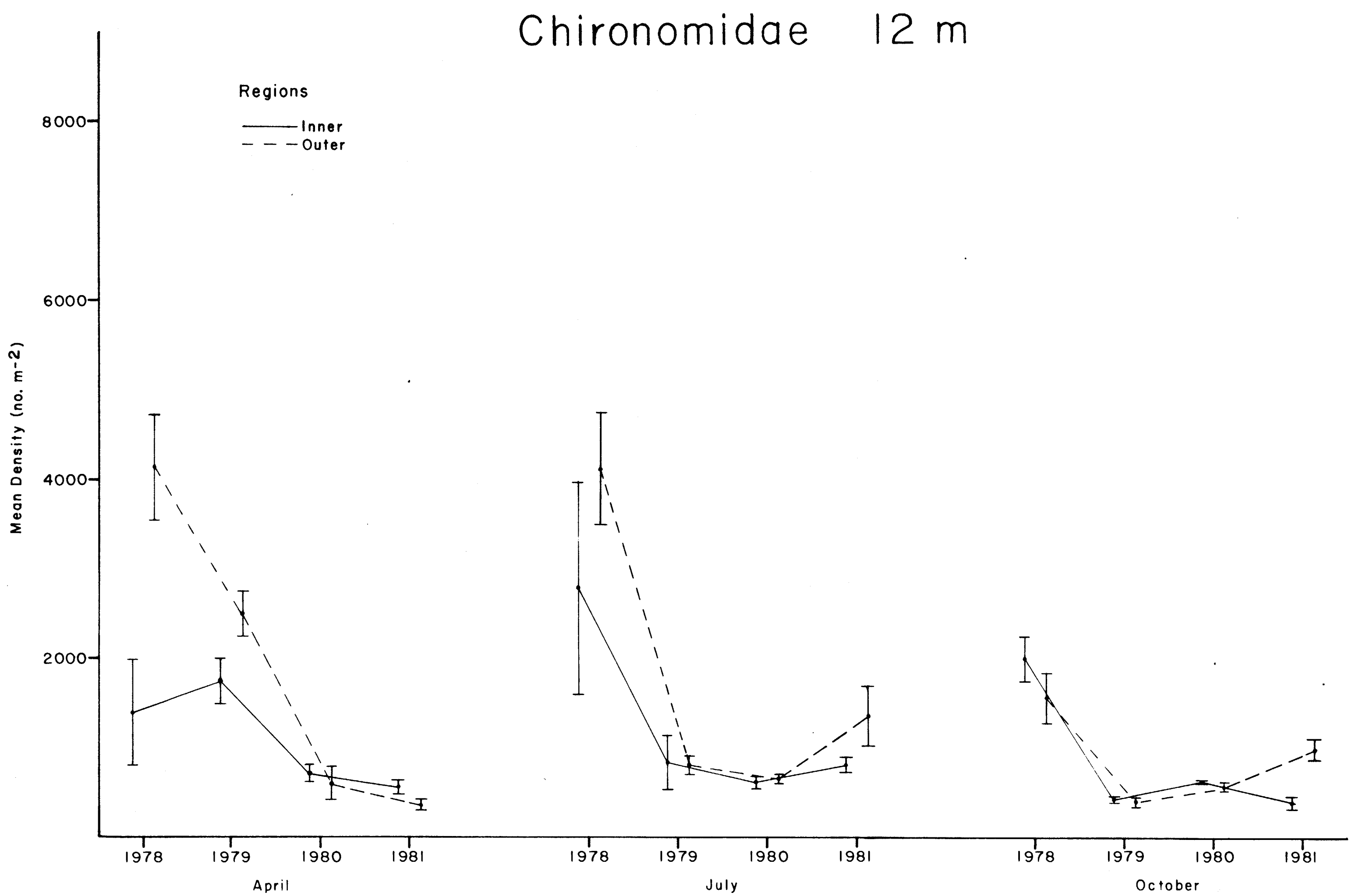

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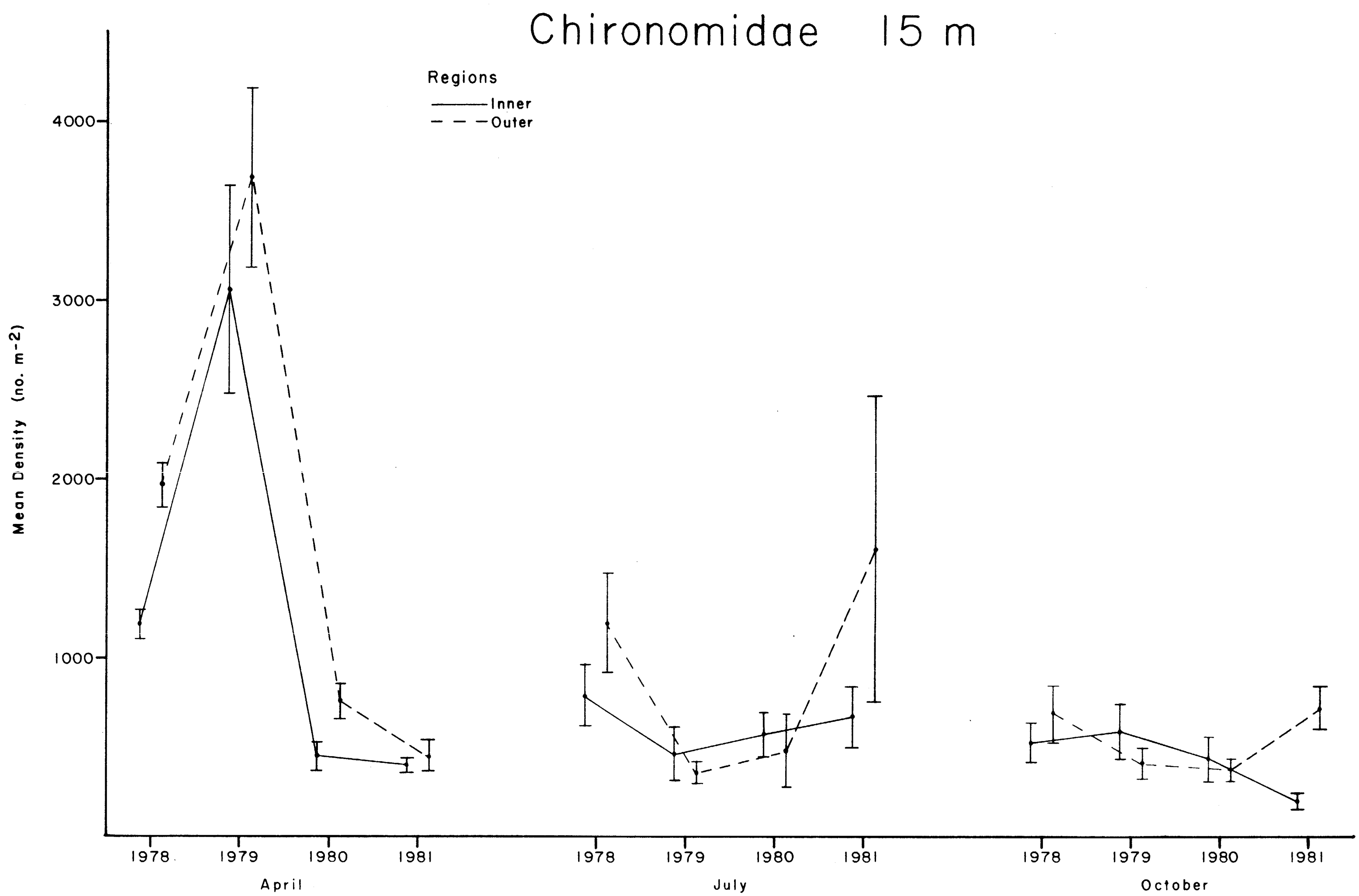


Fig. 7. Continued

Table 8. Analysis of variance results for densities [$\log_{10}(x+1)$] of chironomids occurring at 3-15 m from 1978-1981 near the J.H. Campbell Plant, eastern Lake Michigan [NS = no significance ($p > 0.05$), * = $0.01 < p \leq 0.05$, ** = $0.001 < p \leq 0.01$, *** = $p \leq 0.001$].

Parameter	Sum of squares	Degrees of freedom	Mean square	F-ratio	Signif.
Region(R)	6.11	1	6.11	5.01	NS
Depth(D)	53.66	4	13.41	4.64	*
Month(M)	66.04	2	33.02	6.09	*
Year(Y)	20.33	3	6.78	33.90	***
RD	0.92	4	0.23	0.14	NS
RM	1.33	2	0.67	0.66	NS
DM	116.94	8	14.62	5.87	***
RY	3.65	3	1.22	6.10	***
DY	34.67	12	2.89	14.45	***
MY	32.51	6	5.42	27.10	***
RDM	1.93	8	0.24	0.38	NS
RDY	19.17	12	1.60	8.00	***
RMY	6.08	6	1.01	5.05	***
DMY	59.70	24	2.49	12.45	***
RDMY	15.10	24	0.63	3.15	***
Error	119.46	600	0.20		

Naididae--

Annual naidid abundance with respect to depth was highly variable. Greatest densities were most consistently encountered at 9 to 12 m, but occasional large abundances at 6 and 15 m contributed much to observed variability. Only at 3 m were consistently similar annual densities noted (Fig. 8). Monthly naidid abundances during each year tended to be greatest in July, but were quite variable across years (Fig. 9). Despite these differences, 1981 mean densities by month and depth were not dissimilar to the range of values observed previously. While mean naidid abundance increased 17% during 1981 (1,408 m^{-2}) when compared with a similar estimate from 1978-1981 (1,206 m^{-2}), proportionate increases in each region were similar. Regional comparisons at each depth indicated greatest discrepancies occurred at 3 and 6 m, with remaining depths exhibiting very similar abundances and trends. Regional differences at 3 and 6 m were noted entirely in July. Annual regional differences at 6 m were sporadic and lacked consistency. Similar estimates at 3 m indicated the occurrence of a consistently occurring population in the inner region, but fluctuating numbers in the outer region (Fig. 10, Appendix 3).

The naidid ANOVA indicated very highly significant year, month, and depth main effects as well as interaction terms. However, the region main effect was not significant (Table 9). The R' value (1.30) for the naidid population occurring at 3 to 15 m during 1978-1981 was considerably

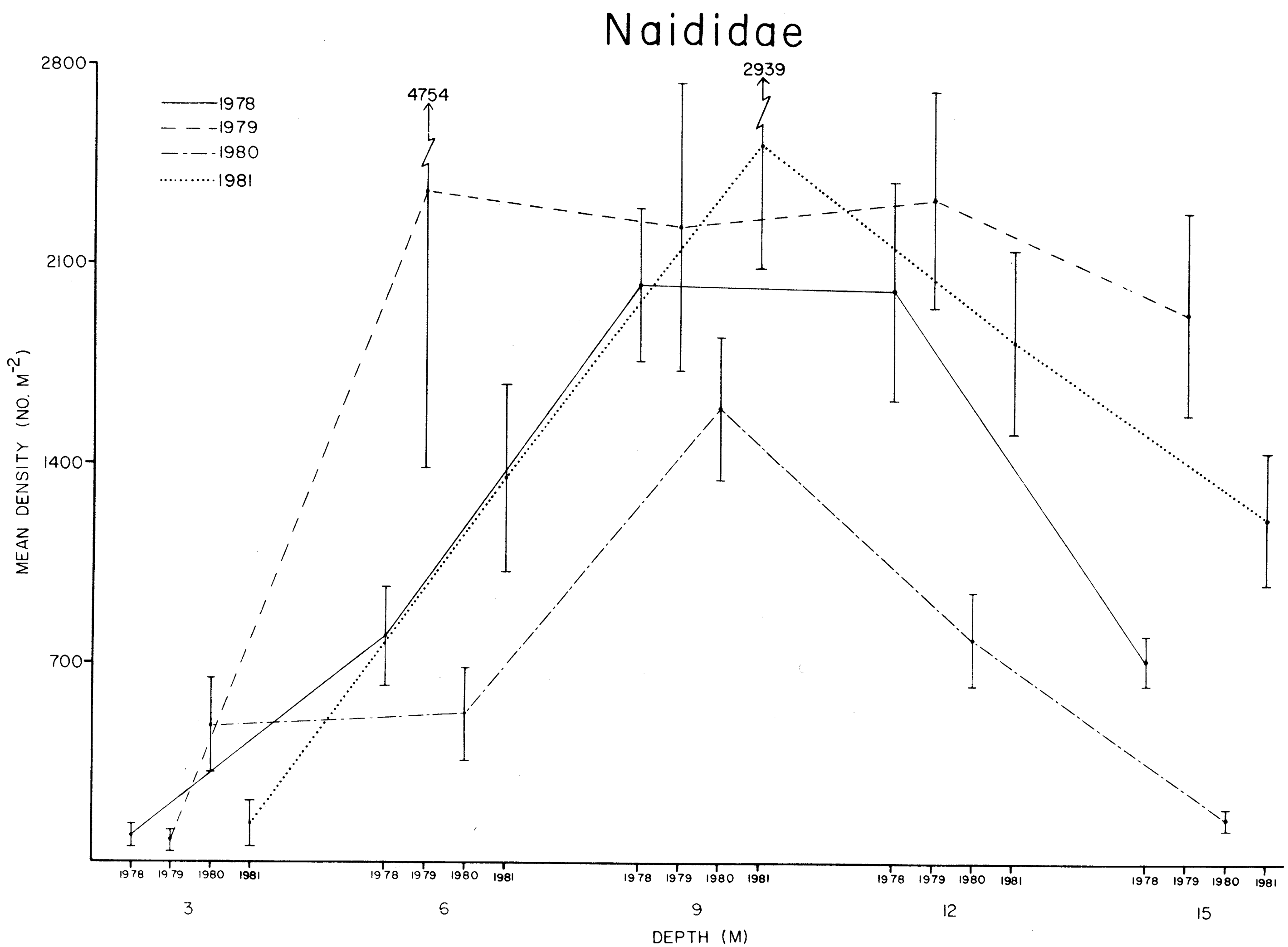


Fig. 8. Mean density (number m^{-2}) of naidids collected at 3-15 m from 1978 through 1981 in eastern Lake Michigan near the J. H. Campbell Plant. Density estimates at each depth were computed by averaging over all months within each year (n = 36). Standard error denoted by vertical bar.

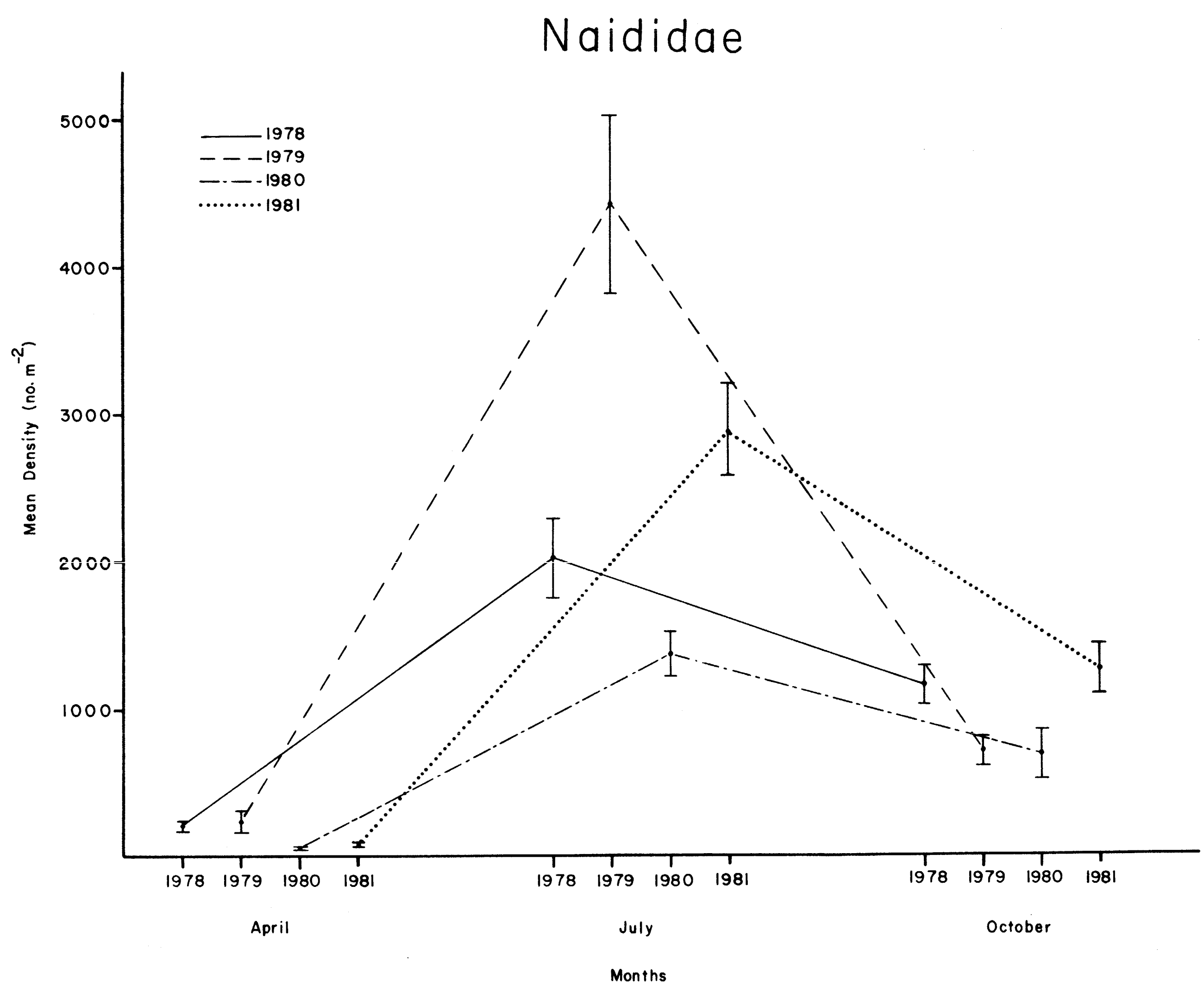


Fig. 9. Mean density (number m^{-2}) of naidids collected during April, July, and October 1978 through 1981 in eastern Lake Michigan near the J. H. Campbell Plant. Density estimates for each month were computed by averaging over all depths within each year (n = 60). Standard error denoted by vertical bar.

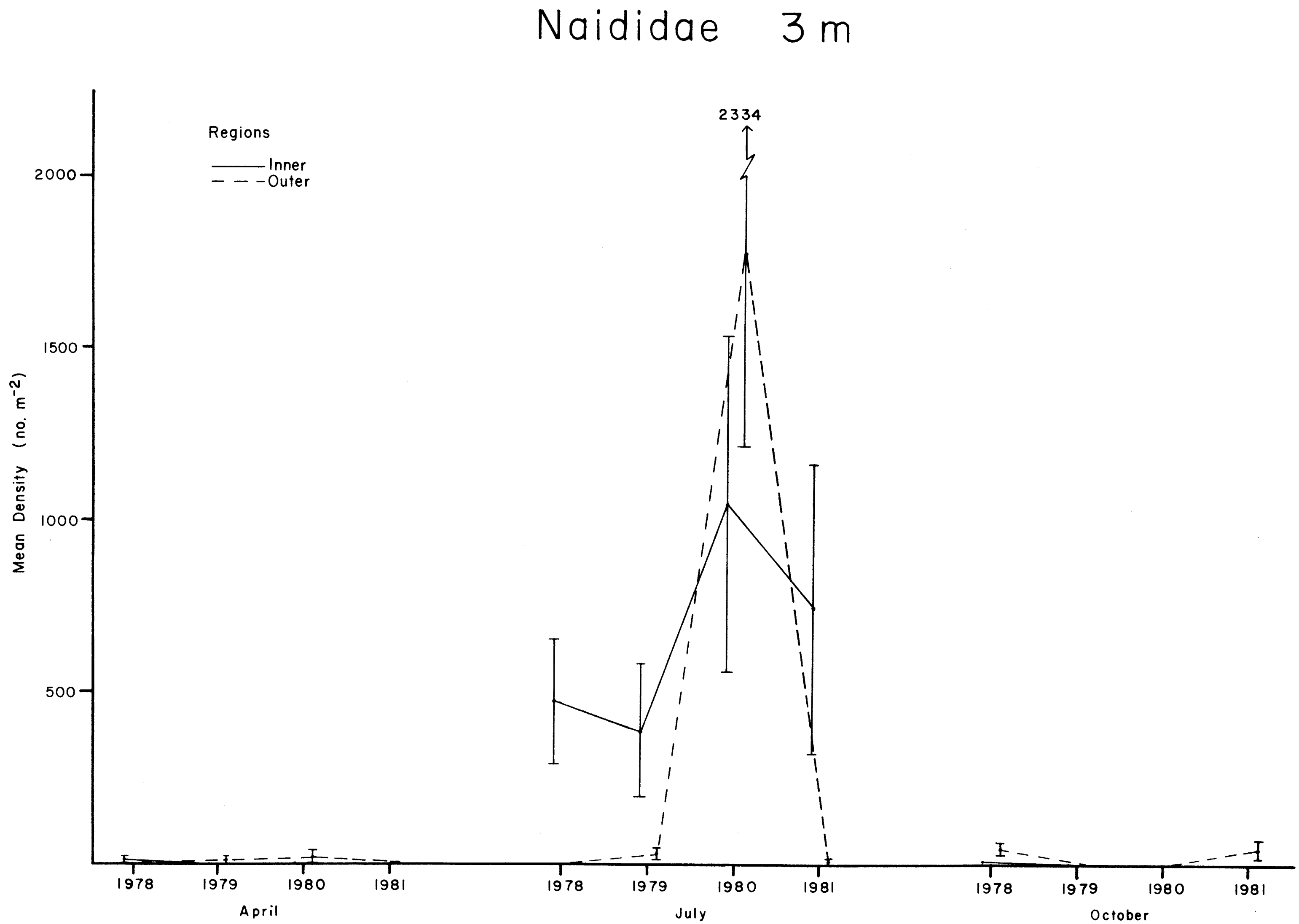
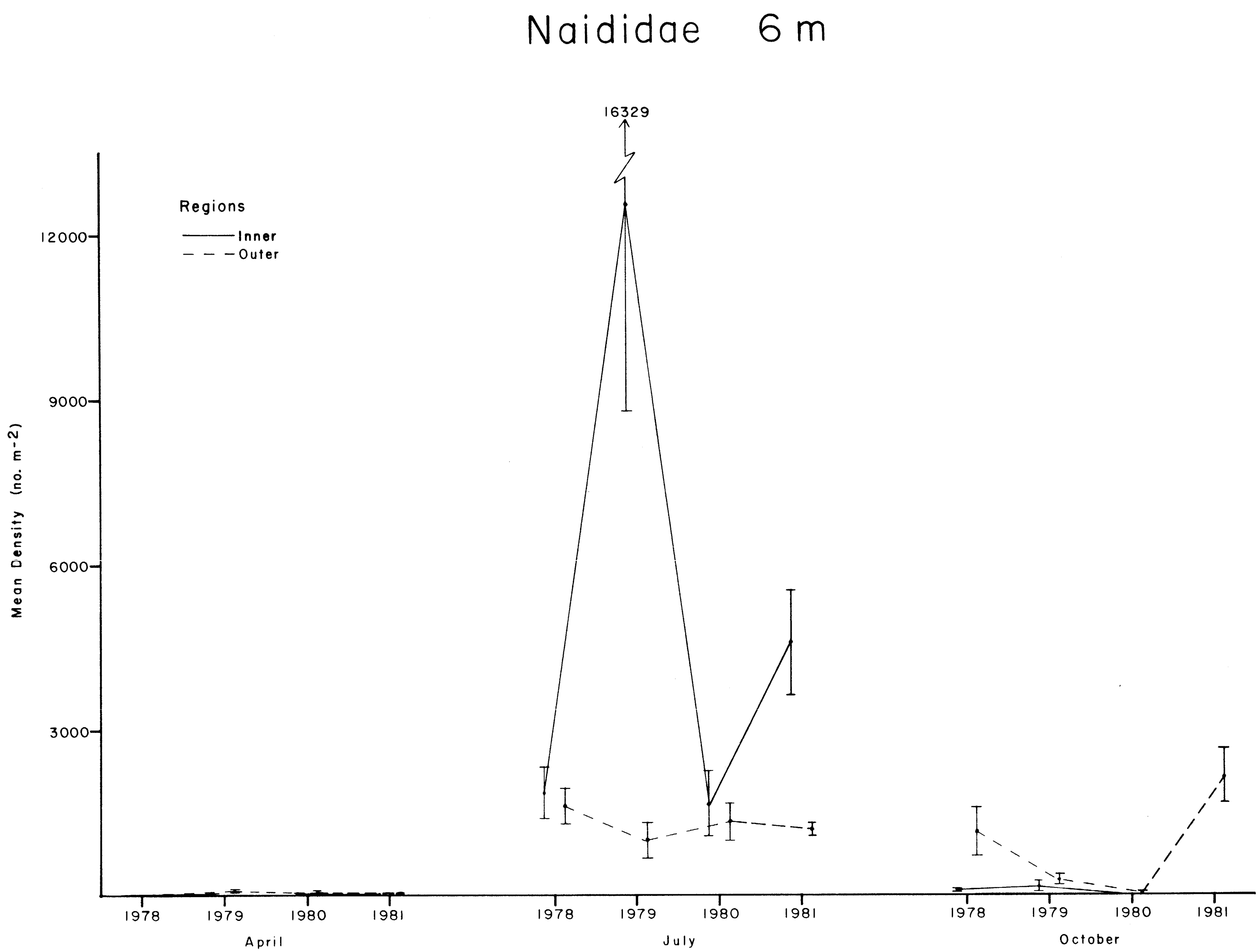


Fig. 10. Inner and outer regional mean densities (number m^{-2}) of naidids collected in April, July, and October 1978 through 1981 from eastern Lake Michigan at 3-15 m near the J. H. Campbell Plant. Standard error denoted by vertical bar (n = 6). Inner region corresponds to treatment area near present thermal discharge. Outer region corresponds to reference area.



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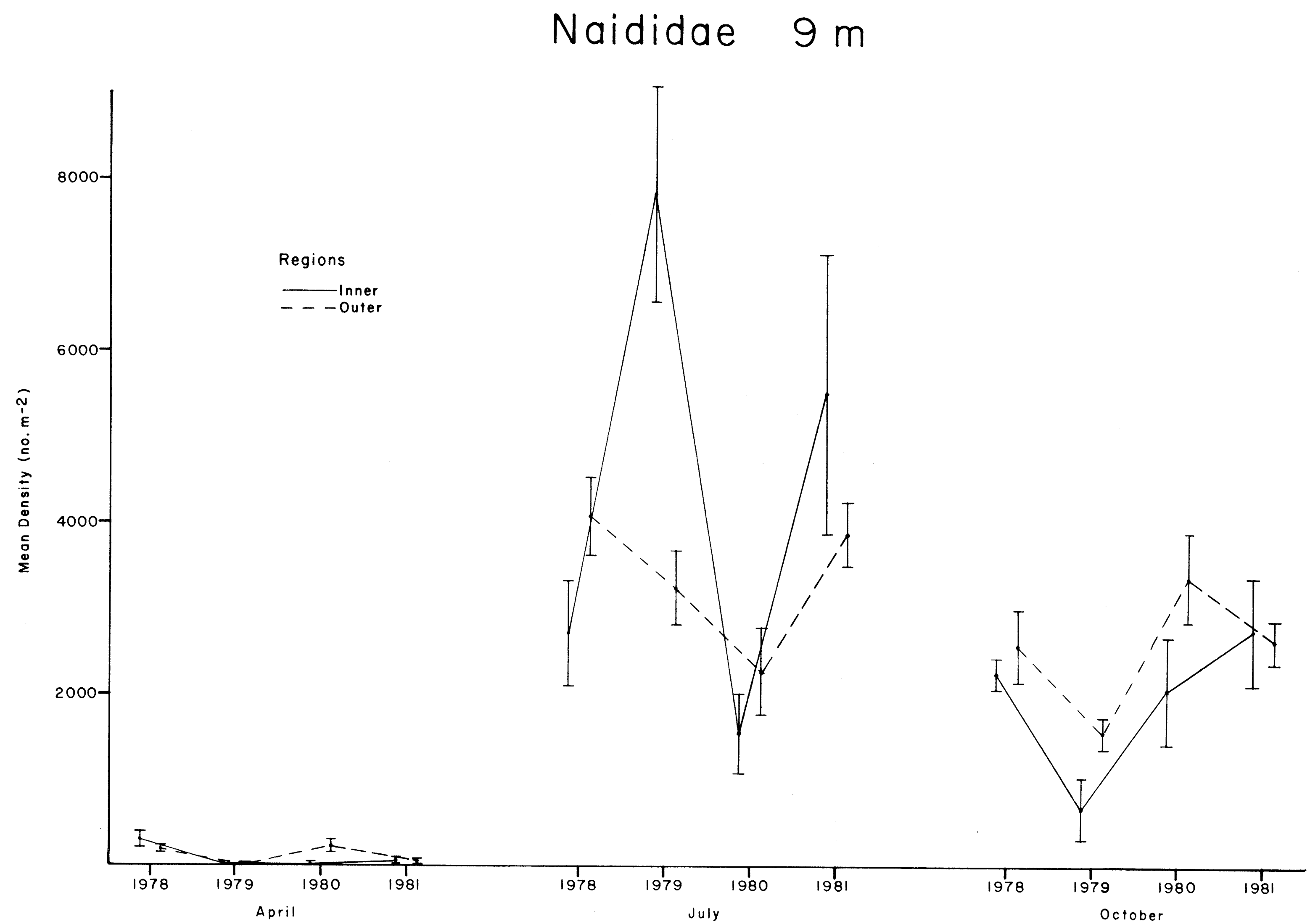

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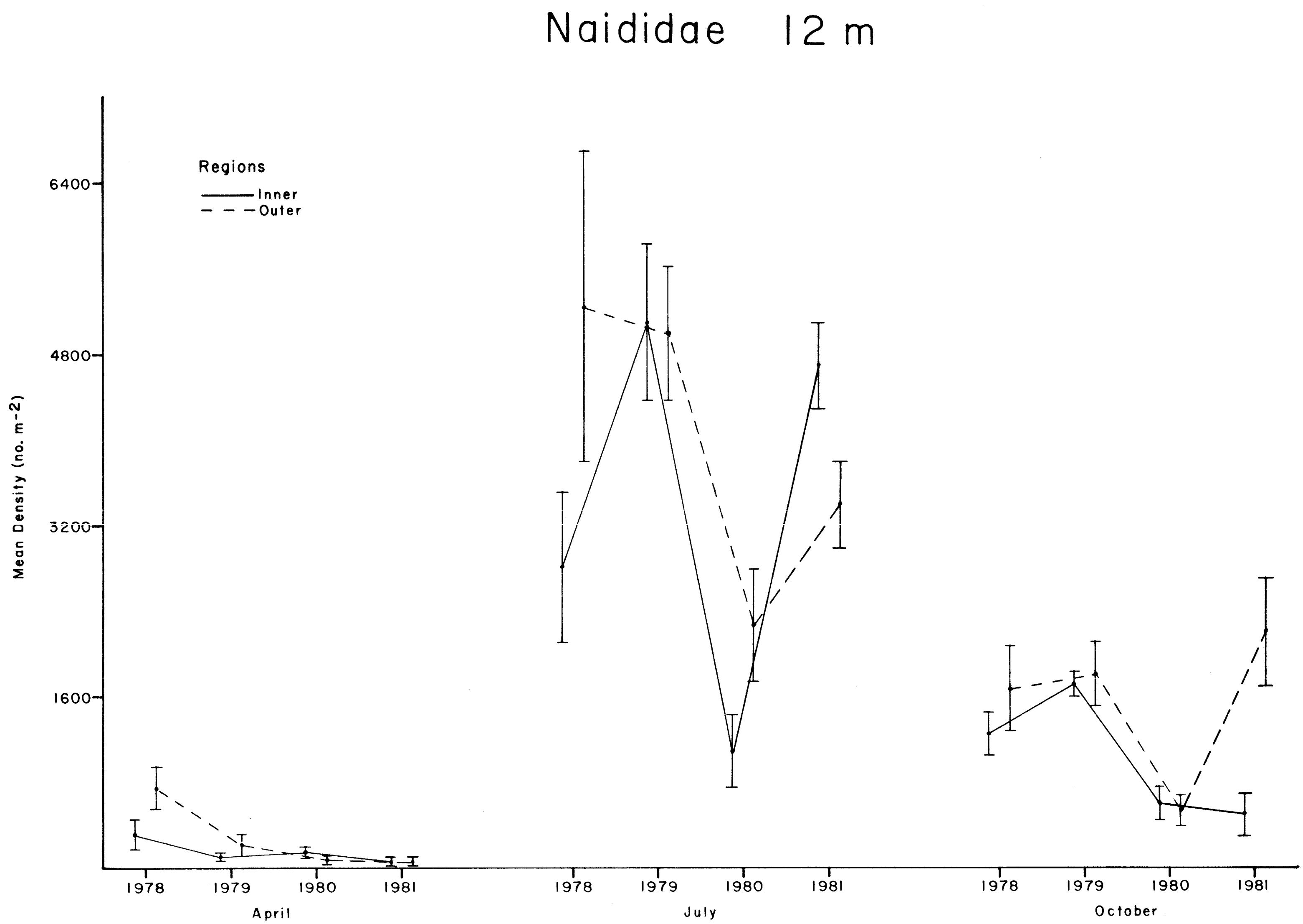

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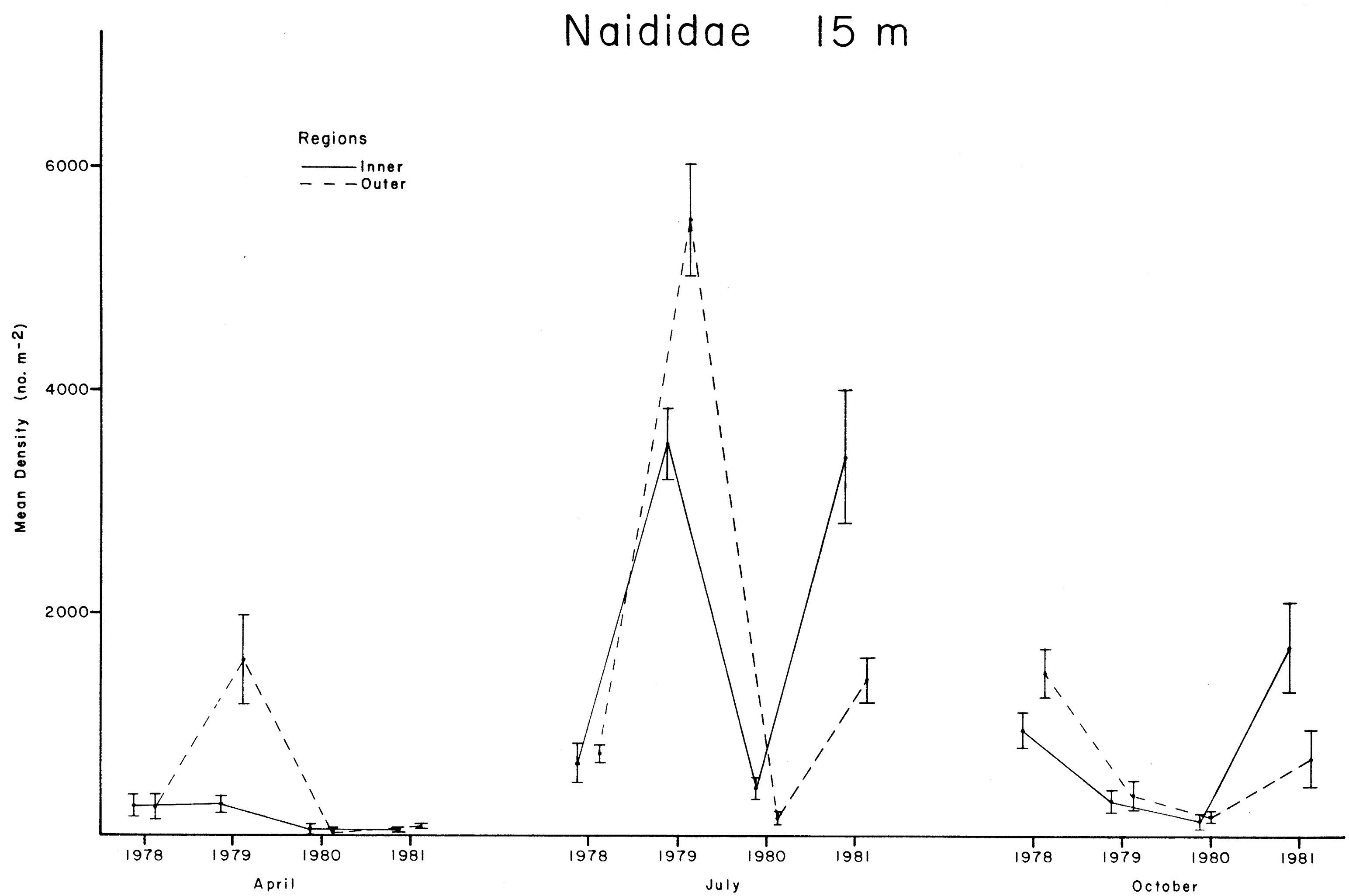


Fig. 10. Continued

Table 9. Analysis of variance results for densities [$\log_{10}(x+1)$] of naidids occurring at 3-15 m from 1978-1981 near the J.H. Campbell Plant, eastern Lake Michigan [NS = no significance ($p > 0.05$), * = $0.01 < p \leq 0.05$, ** = $0.001 < p \leq 0.01$, *** = $p \leq 0.001$].

Parameter	Sum of squares	Degrees of freedom	Mean square	F-ratio	Signif.
Region(R)	2.64	1	2.64	17.60	**
Depth(D)	410.22	4	102.55	24.30	***
Month(M)	436.57	2	218.28	62.54	***
Year(Y)	19.22	3	6.41	13.64	***
RD	13.52	4	3.38	2.82	NS
RM	23.25	2	11.62	8.24	*
DM	70.61	8	8.83	3.25	*
RY	0.45	3	0.15	0.32	NS
DY	50.60	12	4.22	8.98	***
MY	20.95	6	3.49	7.43	***
RDM	20.94	8	2.62	2.32	NS
RDY	14.34	12	1.20	2.55	**
RMY	8.46	6	1.41	3.00	**
DMY	65.36	24	2.72	5.79	***
RDMY	27.17	24	1.13	2.40	***
Error	280.22	600	0.47		

lower than the R value (2.33) (Table 7), indicating no measurable plant effect was associated with naidid density fluctuations.

Tubificidae--

Mean abundance of tubificids during 1981 increased 108% from the 1978-1980 preoperational average density of 749 m^{-2} to 1,547 m^{-2}. Annual tubificid densities during preoperational years were quite similar with a range of only 627 to 886 m^{-2}. Although tubificid populations tended to be quite patchy and contagiously distributed, the homogeneous, fine sandy substrate type which generally lacked significant quantities of silt may have influenced the observed low annual densities and variability of tubificids. Nonetheless, within certain depths and months annual variability was quite high, particularly at 12 and 15 m (Fig. 11), and during July (Fig. 12). Results from the tubificid ANOVA based on population densities occurring at 9 to 15 m indicated significant annual and monthly density differences, no significant difference among depths, but highly significant higher-order interactions (Table 10). Generally, within the 9- to 15-m depths, abundance of tubificids was quite similar (Fig. 11). A significant difference among regional tubificid abundances confirmed the previously observed trend of outer region tubificid densities being greater than those in the inner region. This trend was observed consistently at all depths. While the absolute number of tubificids in each region differed, density trends were generally similar even though the trend in the outer region was more pronounced, particularly at 9 and 12 m (Fig. 13, Appendix 3). No definitive explanation

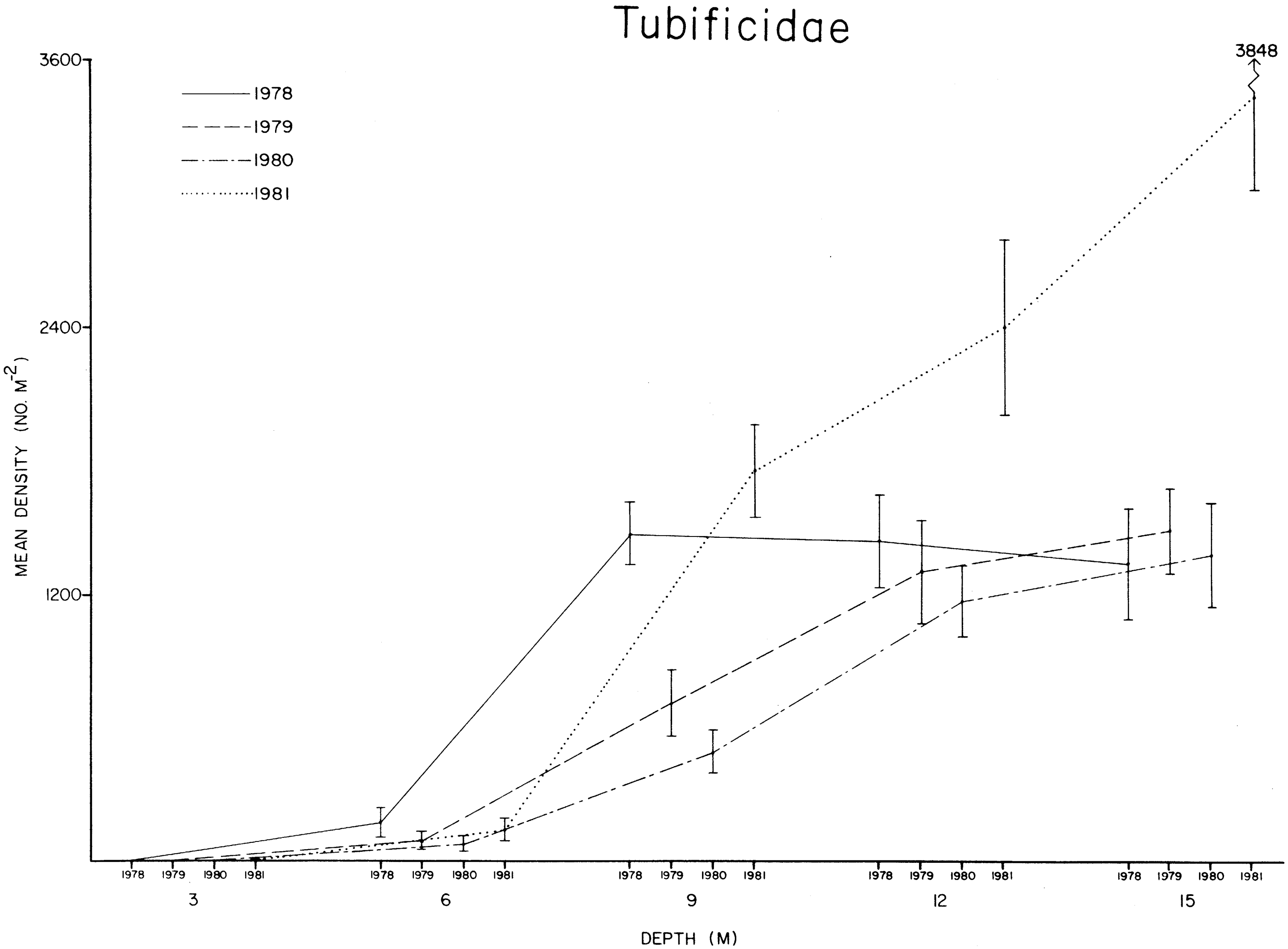


Fig. 11. Mean density (number m^{-2}) of tubificids collected at 3-15 m from 1978 through 1981 in eastern Lake Michigan near the J. H. Campbell Plant. Density estimates at each depth were computed by averaging over all months within each year (n = 36). Standard error denoted by vertical bar.

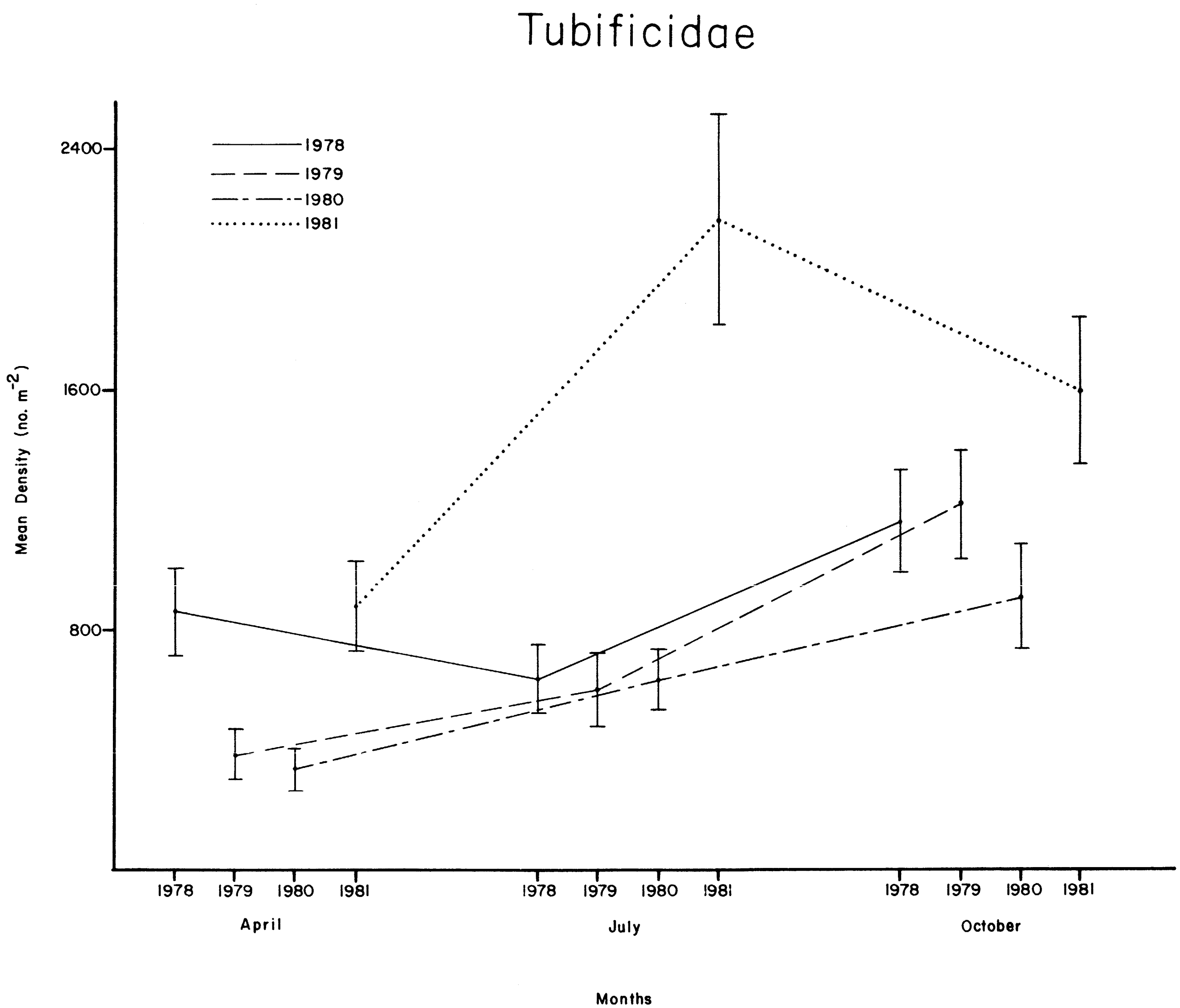


Fig. 12. Mean density (number m^{-2}) of tubificids collected during April, July, and October 1978 through 1981 in eastern Lake Michigan near the J. H. Campbell Plant. Density estimates for each month were computed by averaging over all depths within each year (n = 60). Standard error denoted by vertical bar.

Table 10. Analysis of variance results for densities [$\log_{10}(x+1)$] of tubificids occurring at 9-15 m from 1978-1981 near the J.H. Campbell Plant, eastern Lake Michigan [NS = no significance ($p > 0.05$), * = $0.01 < p \leq 0.05$, ** = $0.001 < p \leq 0.01$, *** = $p \leq 0.001$].

Parameter	Sum of squares	Degrees of freedom	Mean square	F-ratio	Signif.
Region(R)	18.06	1	18.06	13.18	*
Depth(D)	7.19	2	3.60	1.46	NS
Month(M)	19.55	2	9.77	5.65	*
Year(Y)	20.93	3	6.98	15.17	***
RD	2.53	2	1.27	0.76	NS
RM	0.41	2	0.20	0.50	NS
DM	3.09	4	0.77	1.24	NS
RY	4.10	3	1.37	2.98	*
DY	14.79	6	2.46	5.35	***
MY	10.40	6	1.73	3.76	***
RDM	1.27	4	0.32	0.23	NS
RDY	10.10	6	1.68	3.65	**
RMY	2.41	6	0.40	0.87	NS
DMY	7.42	12	0.62	1.35	NS
RDMY	16.86	12	1.40	3.04	***
Error	167.21	360	0.46		

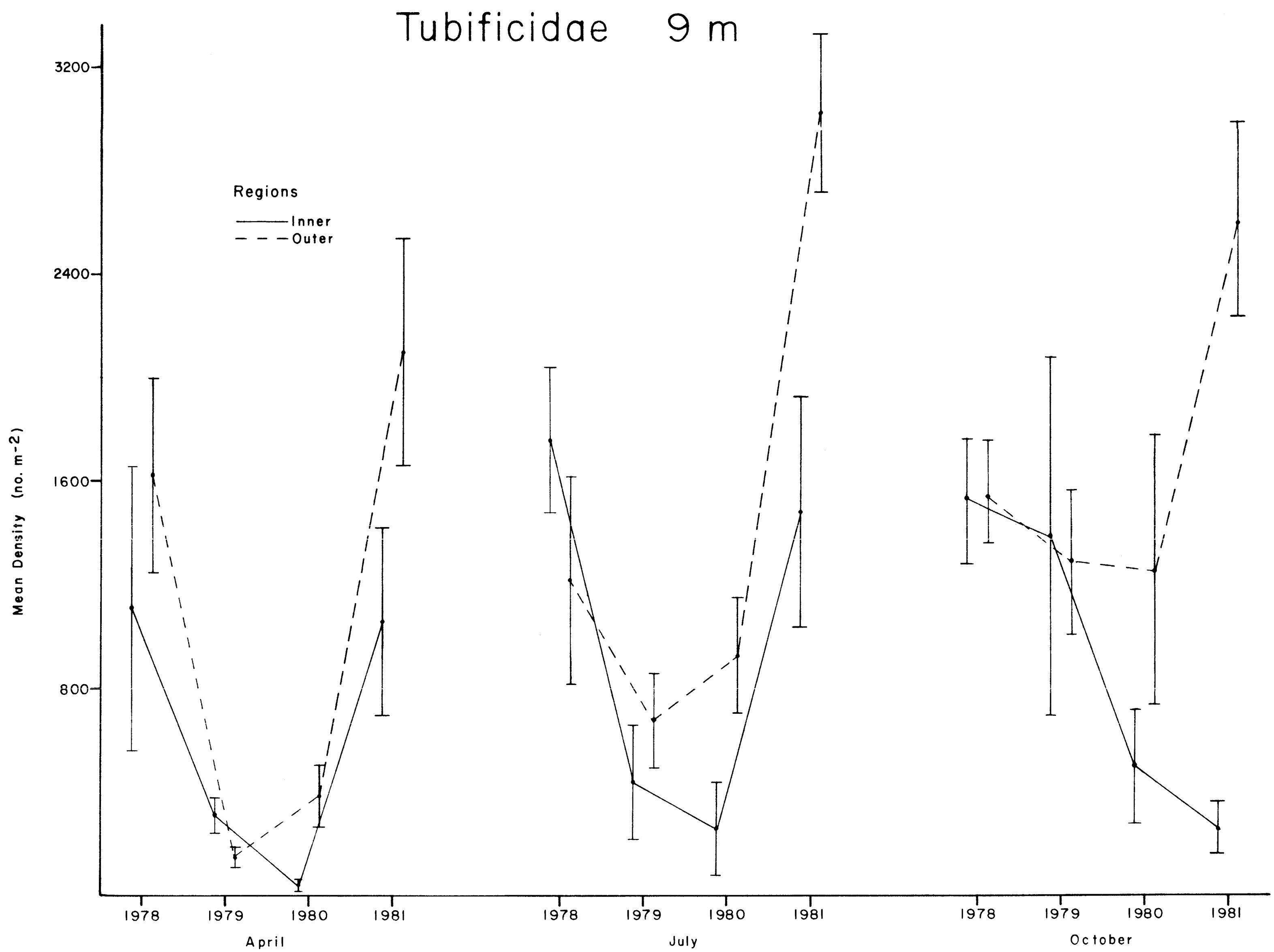
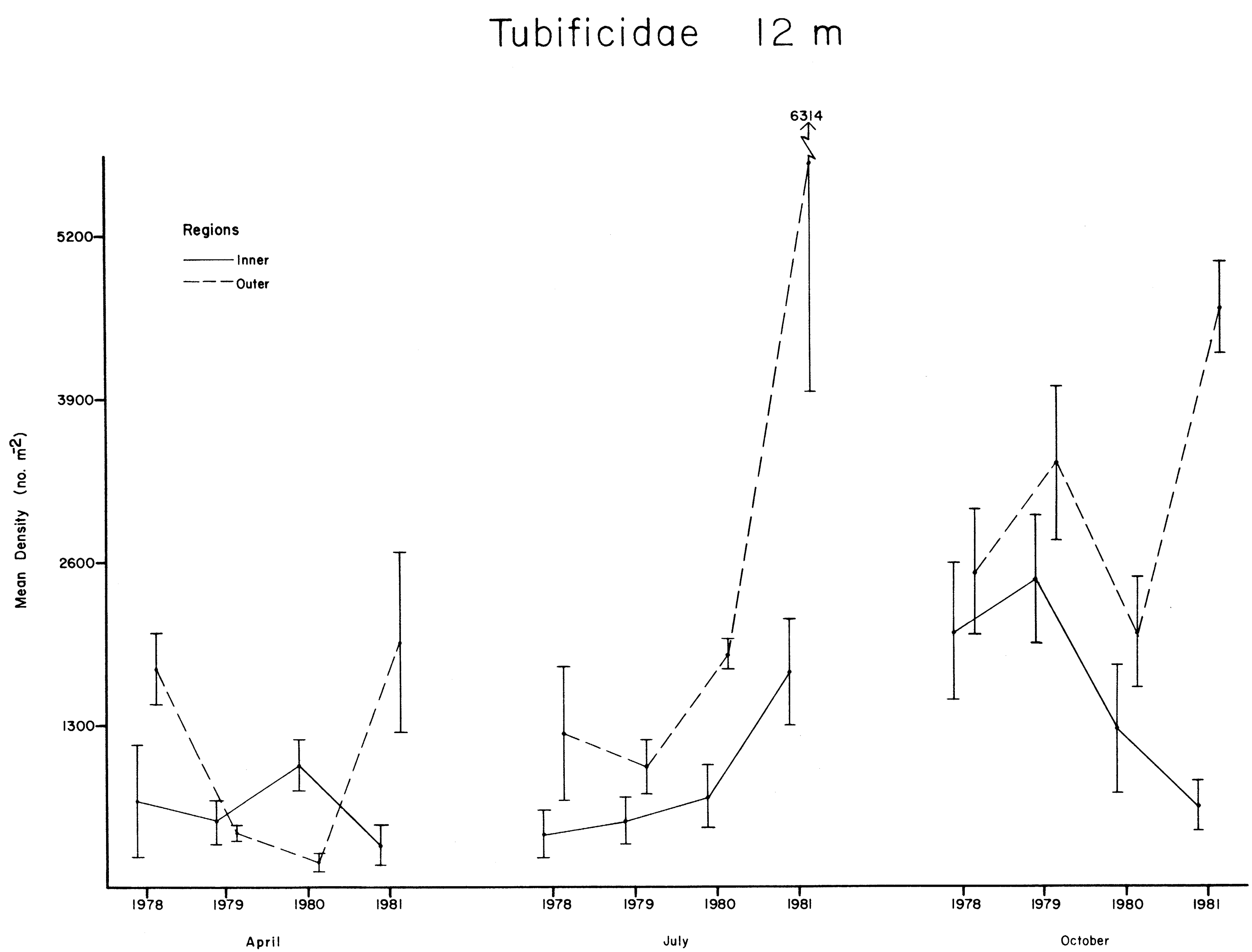


Fig. 13. Inner and outer regional mean densities (number m^{-2}) of tubificids collected in April, July, and October 1978 through 1981 from eastern Lake Michigan at 9-15 m near the J. H. Campbell Plant. Standard error denoted by vertical bar (n = 6). Inner region corresponds to treatment area near present thermal discharge. Outer region corresponds to reference area.



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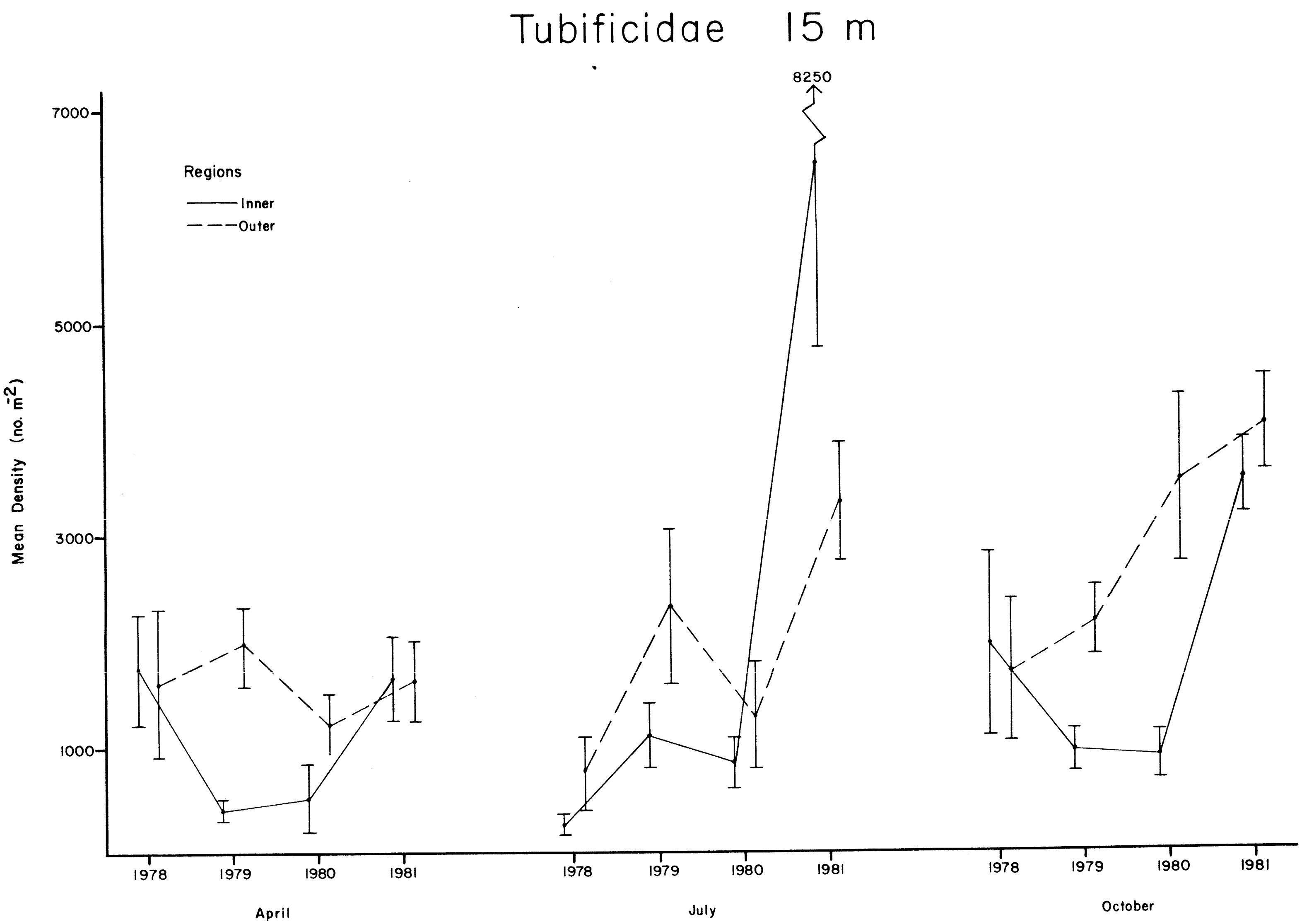

Fig. 13. Continued

can be offered to explain the regional difference, except that the difference was a regional dissimilarity inherent at the start of the study. Nonetheless, it was evident that despite this initial regional difference, no measurable heat effect due to plant operation was associated with density changes observed in the tubificid population at 9-15 m during 1978-1981, since the R' value (1.54) was much lower than the R value (2.98) (Table 7).

Enchytraeidae--

The 1981 average number of enchytraeids (128 m^{-2}) was the same as the 1978-1980 preoperational mean density. Likewise, mean density at each depth and average monthly abundance during 1981 were quite similar to the previously observed range of values. Greatest enchytraeid abundance was observed at 12 and 15 m (Fig. 14). As very few enchytraeids were encountered at depths less than 9 m, the enchytraeid ANOVA considered only the 9- to 15-m population densities. Although there was little difference among monthly density estimates for enchytraeids, there was a slight increase from April to July and October, which had fairly similar enchytraeid densities (Fig. 15).

Based on the enchytraeid ANOVA, there were significant year, depth, and regional main effects, no significant monthly differences, and variable significance among higher-order interactions for population densities occurring at 9 to 15 m (Table 11). Examination of regional enchytraeid density trends at 9 to 15 m suggested only occasional strong regional differences, primarily during October at 9 and 12 m and April at 15 m (Fig. 16, Appendix 3). However, overall operational-regional density differences were negligible. As the R' value (2.81) was below the detection limit of the ANOVA (R = 3.81) (Table 7), no measurable plant effect was associated with the enchytraeid population occurring at 9 to 15 m from 1978-1981 near the Campbell Plant.

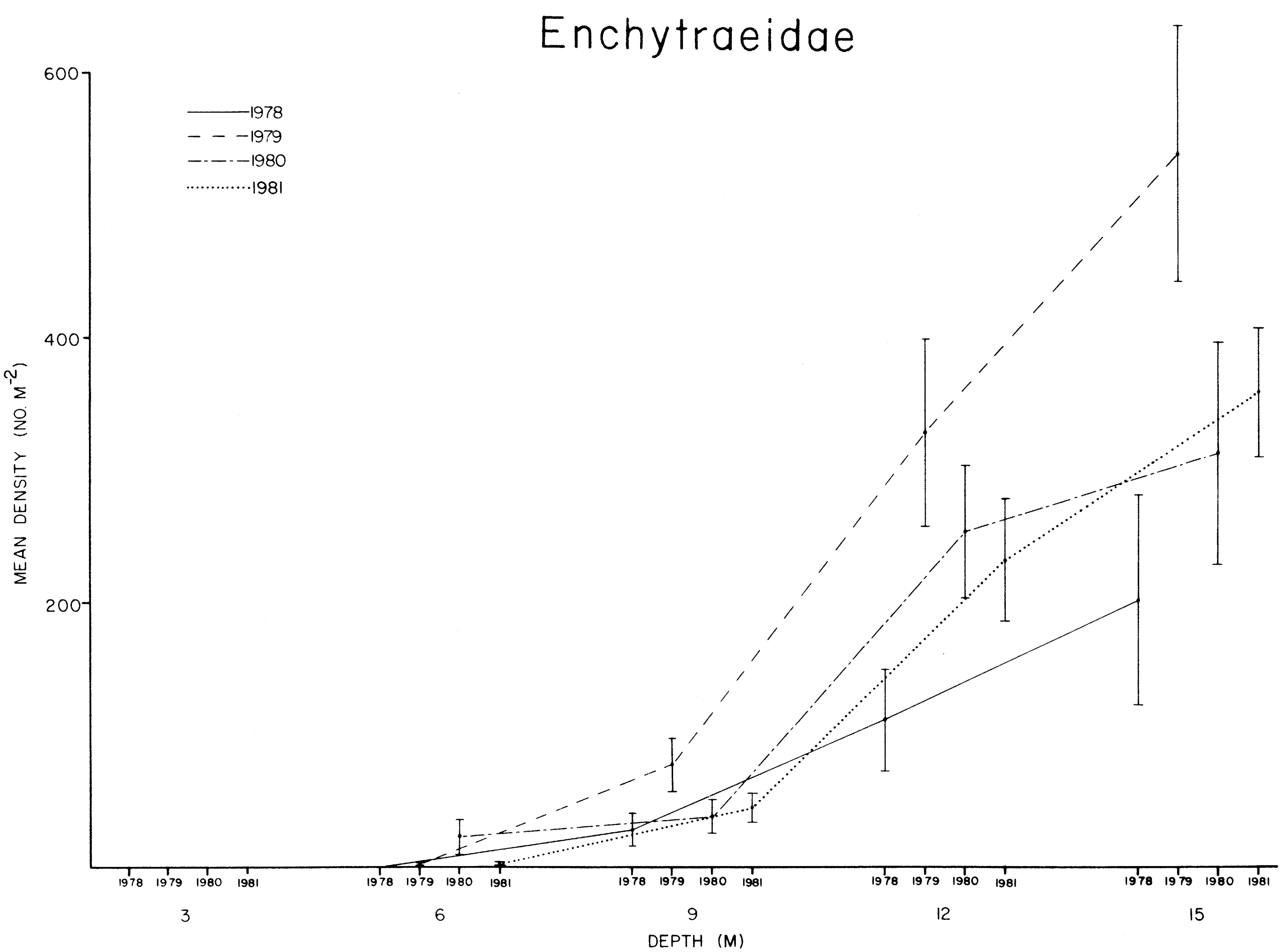

Fig. 14. Mean density (number m^{-2}) of enchytraeids collected at 3-15 m from 1978 through 1981 in eastern Lake Michigan near the J. H. Campbell Plant. Density estimates at each depth were computed by averaging over all months within each year (n = 36). Standard error denoted by vertical bar.

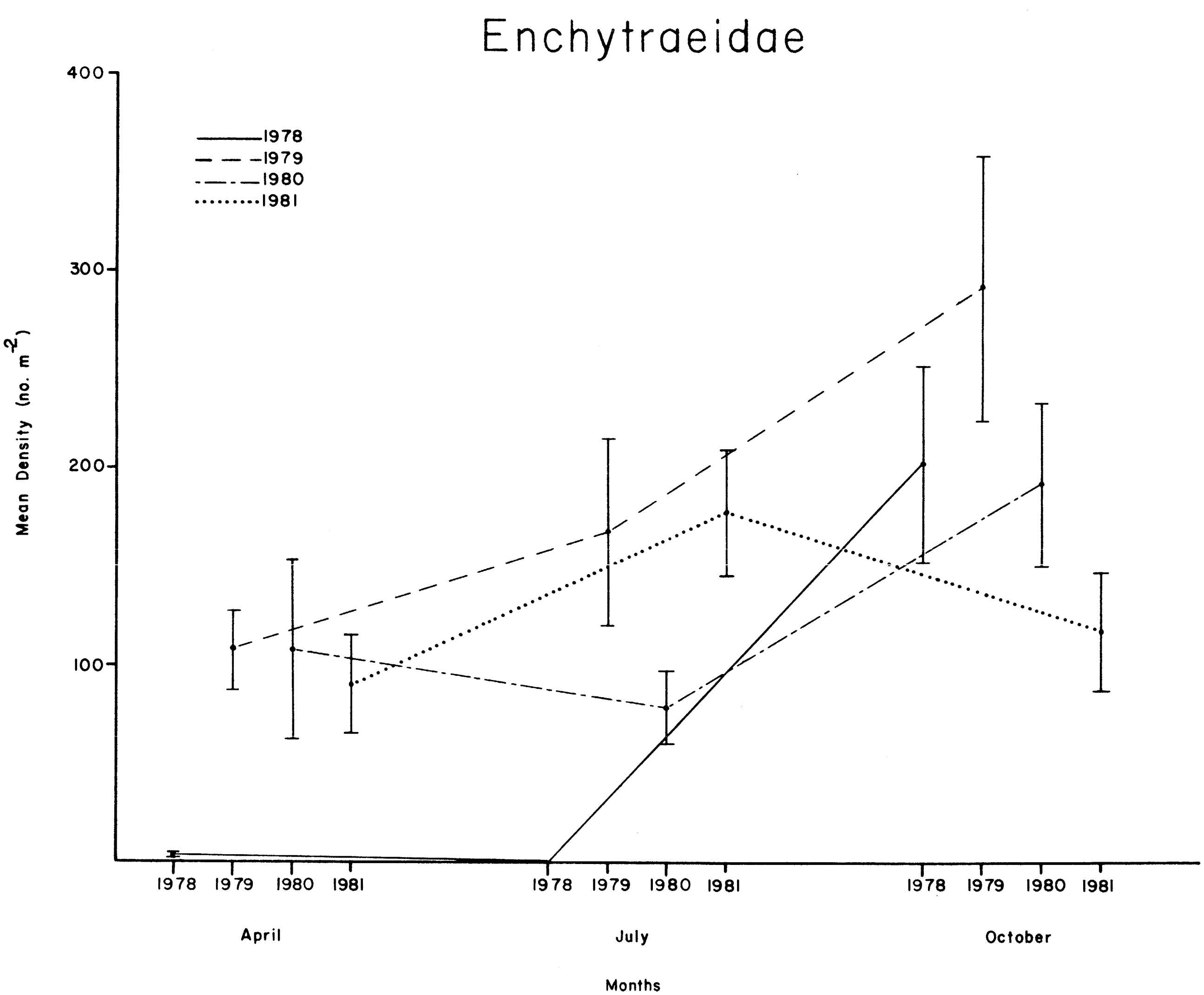

Fig. 15. Mean density (number m^{-2}) of enchytraeids collected during April, July, and October 1978 through 1981 in eastern Lake Michigan near the J. H. Campbell Plant. Density estimates for each month were computed by averaging over all depths within each year (n = 60). Standard error denoted by vertical bar.

Table 11. Analysis of variance results for densities [$\log_{10}(x+1)$] of enchytraeids occurring at 9-15 m from 1978-1981 near the J.H. Campbell Plant, eastern Lake Michigan [NS = no significance ($p > 0.05$), * = $0.01 < p \leq 0.05$, ** = $0.001 < p \leq 0.01$, *** = $p \leq 0.001$].

Parameter	Sum of squares	Degrees of freedom	Mean square	F-ratio	Signif.
Region(R)	27.48	1	27.48	12.55	*
Depth(D)	74.90	2	37.48	10.12	*
Month(M)	48.47	2	24.23	2.64	NS
Year(Y)	71.17	3	23.72	33.89	***
RD	1.96	2	0.98	0.80	NS
RM	2.56	2	1.28	0.56	NS
DM	14.26	4	3.57	2.63	NS
RY	6.57	3	2.19	3.13	*
DY	22.20	6	3.70	5.29	***
MY	55.07	6	9.18	13.11	***
RDM	13.45	4	3.36	1.80	NS
RDY	7.37	6	1.23	1.76	NS
RMY	13.71	6	2.29	3.27	**
DMY	16.35	12	1.36	1.94	*
RDMY	22.42	12	1.87	2.67	**
Error	252.14	360	0.70		

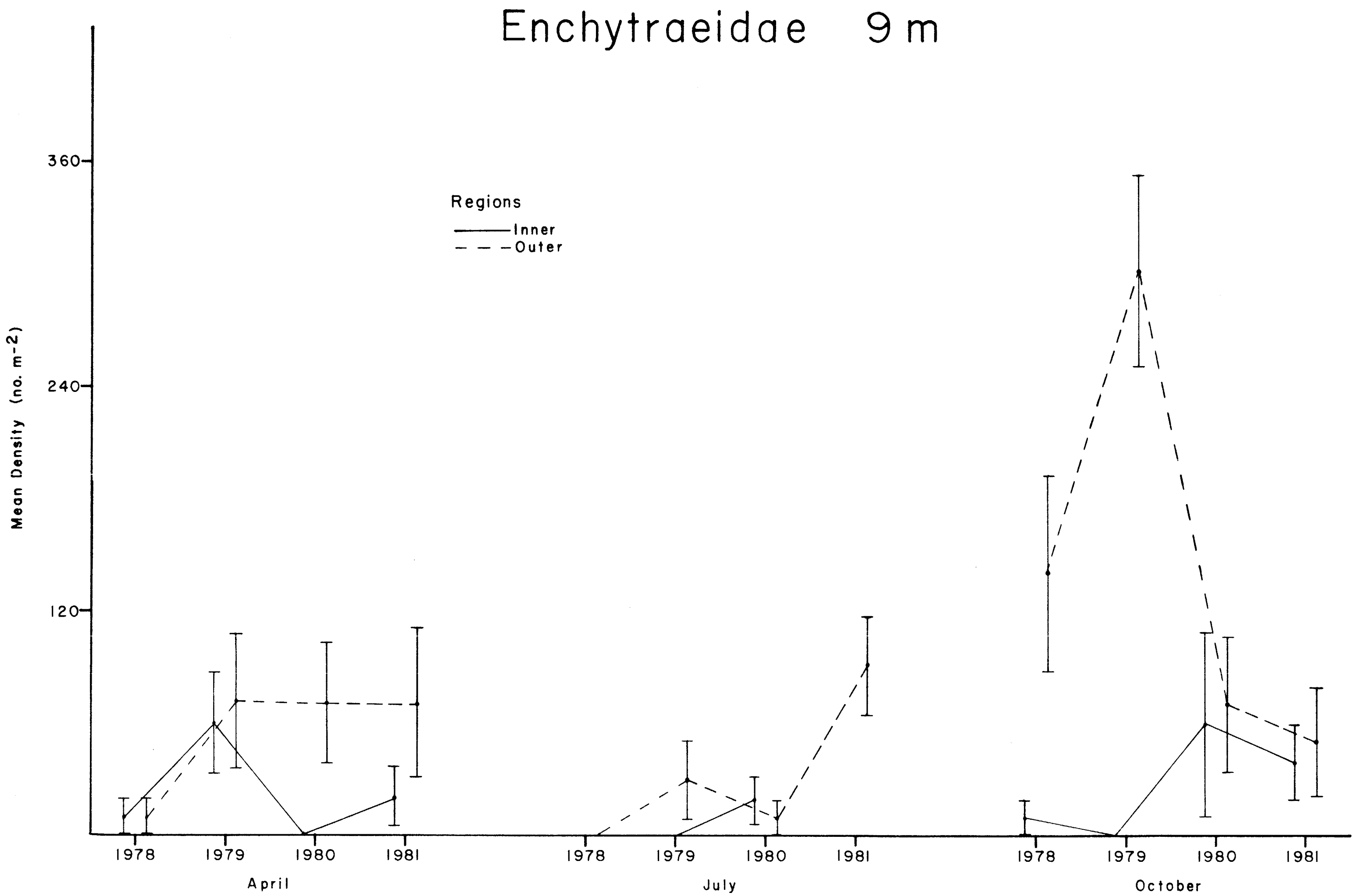

Fig. 16. Inner and outer regional mean densities (number m^{-2}) of enchytraeids collected in April, July, and October 1978 through 1981 from eastern Lake Michigan at 9-15 m near the J. H. Campbell Plant. Standard error denoted by vertical bar (n = 6). Inner region corresponds to treatment area near present thermal discharge. Outer region corresponds to reference area.

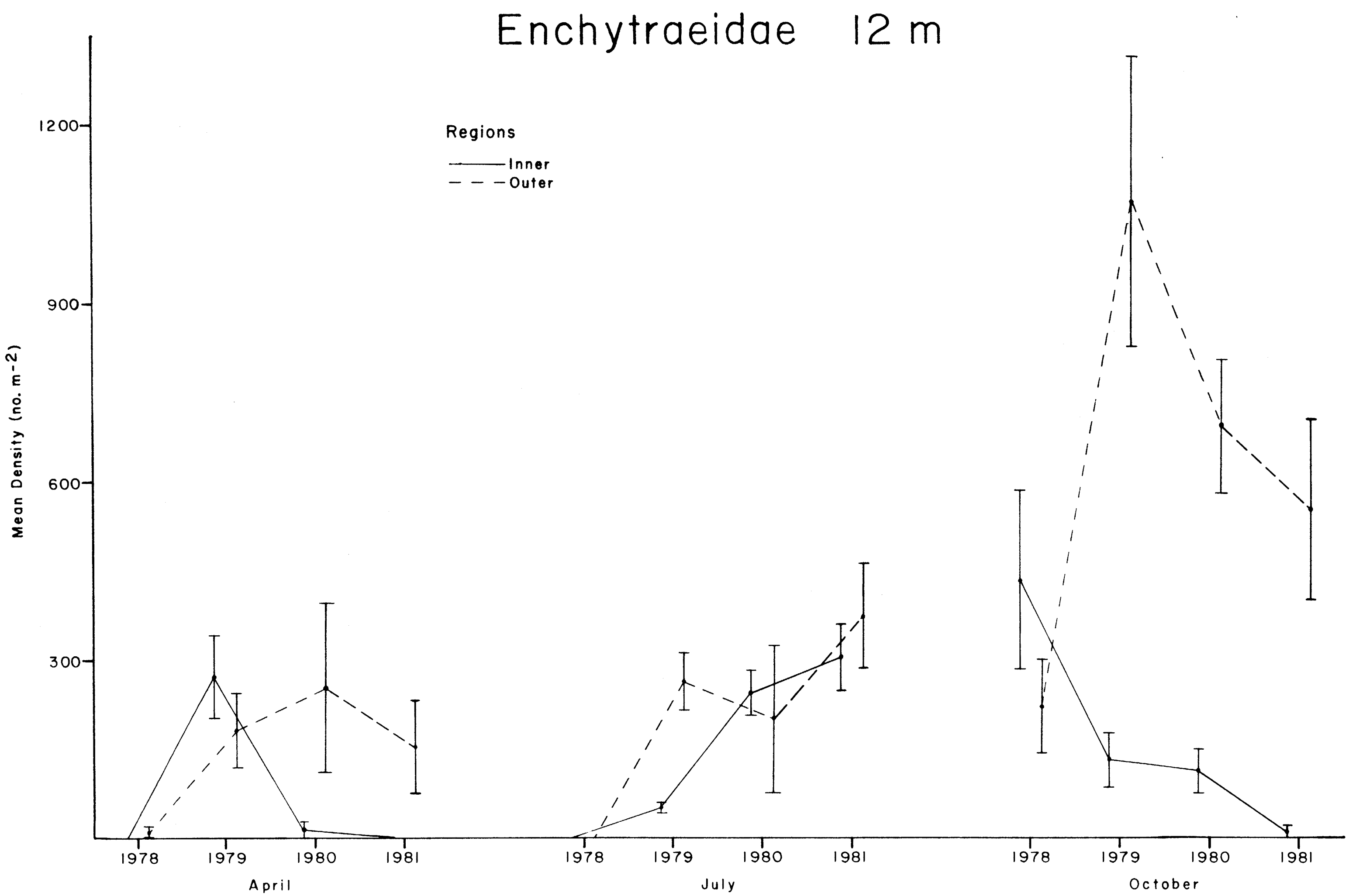

Fig. 16. Continued

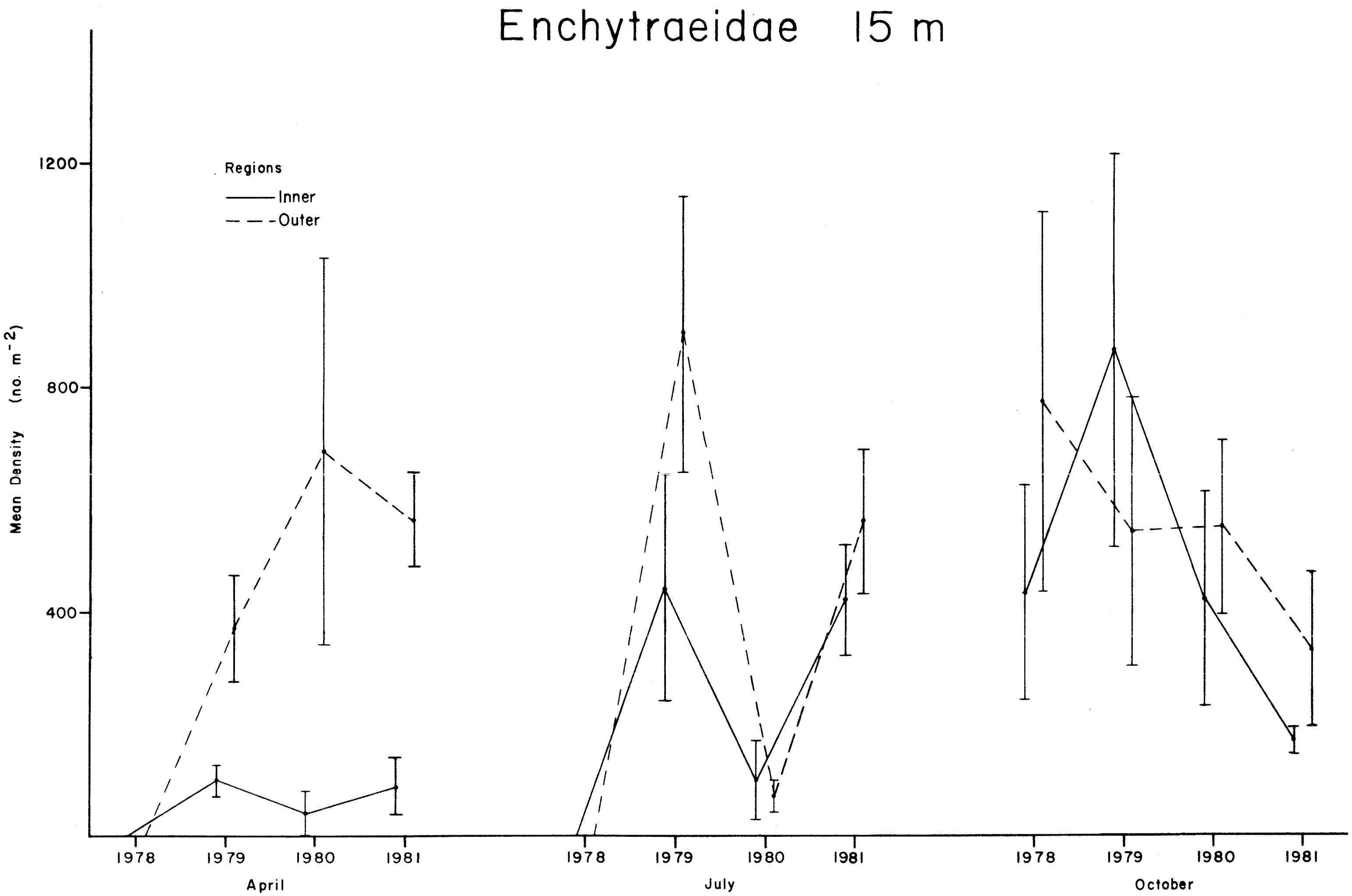

Fig. 16. Continued

Stylodrilus heringianus--

During 1981, as was observed during the previous years, *S. heringianus* was found consistently only at 15 m (Fig. 17). A large increase in the mean density of *S. heringianus* during 1981 (252 m^{-2}) compared with the 1978-1980 preoperational average density (128 m^{-2}) resulted from an unusually high number of individuals encountered during July, 1981 (Fig. 18). When comparing 1981 regional abundances of *S. heringianus* with the 1978-1980 regional averages, mean density increased 108% in the outer region, but only 14% in the inner region. This regional difference was mostly attributable to densities encountered in the outer region at 15 m during July (Fig. 19, Appendix 3). In addition, there continued to be a regional density difference in October at the same depth. While this trend clearly supported an apparent regional difference favoring higher abundances of *S. heringianus* in the outer region than in the inner region, the regional main effect in the ANOVA was not significant (Table 12). Both year and month effects were significant. The value of R (13.35) (Table 7) was very high by comparison with those determined for other taxa, but likely reflected the high degree of variability one would expect of a population occurring at the nearshore extent of the main body of the population. A similar calculation of R at the Cook Plant for *S. heringianus* occurring in an increasingly more favorable habitat at 16 to 24 m was 6.70 (unpublished data, GLRD). The R' value of 1.24 indicated

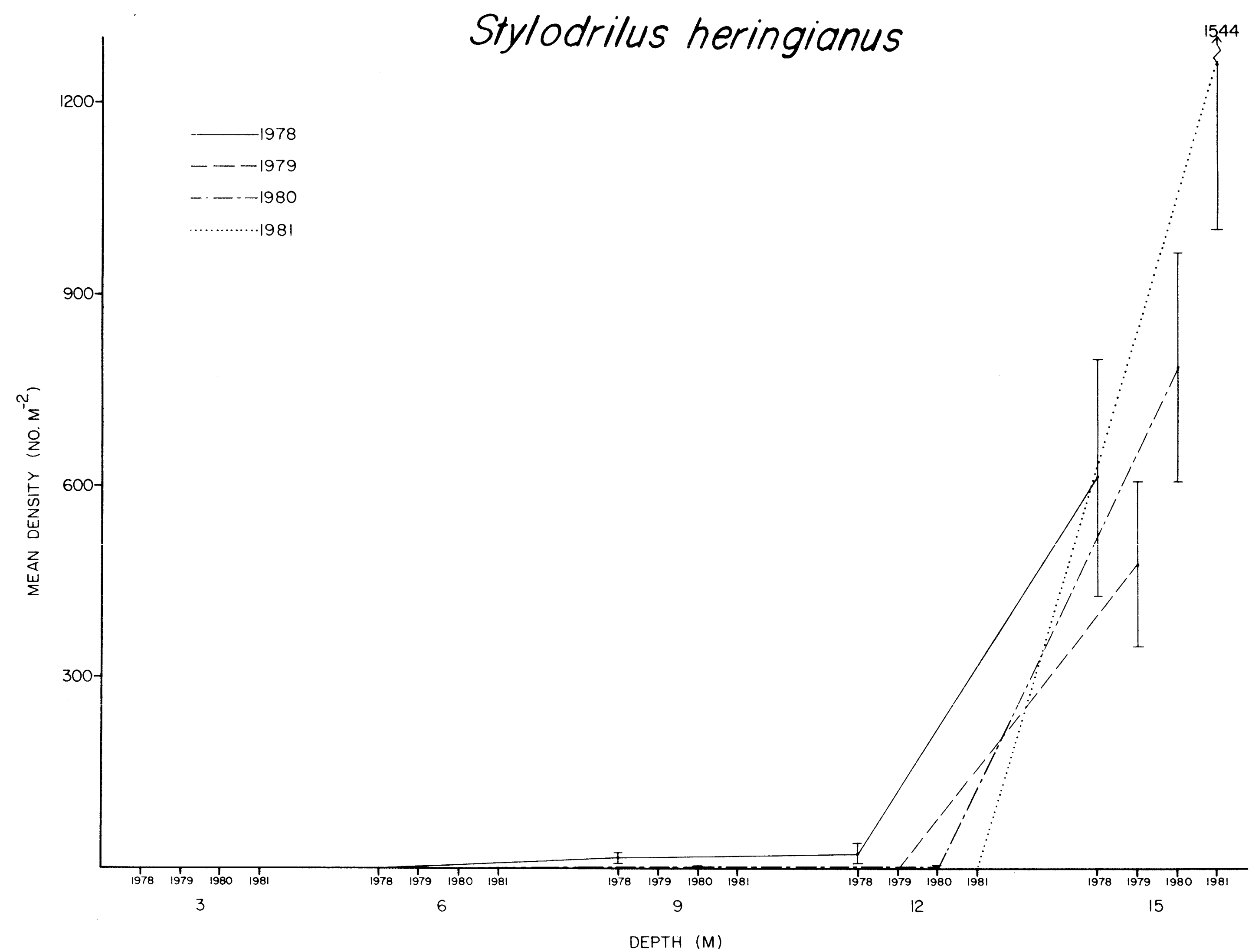

Fig. 17. Mean density (number m^{-2}) of S. heringianus collected at 3-15 m from 1978 through 1981 in eastern Lake Michigan near the J. H. Campbell Plant. Density estimates at each depth were computed by averaging over all months within each year (n = 36). Standard error denoted by vertical bar.

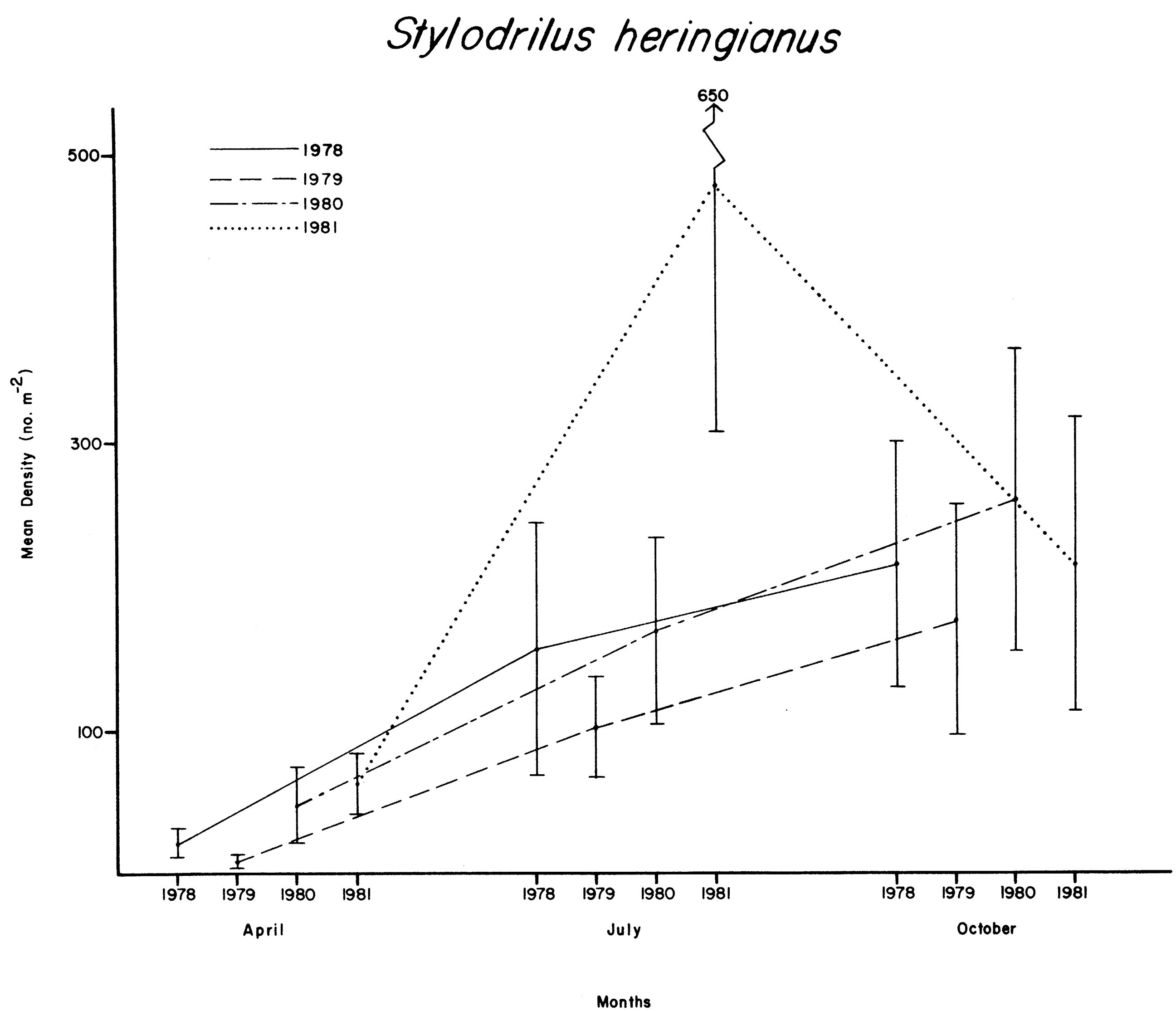

Fig. 18. Mean density (number m^{-2}) of S. heringianus collected during April, July, and October 1978 through 1981 in eastern Lake Michigan near the J. H. Campbell Plant. Density estimates for each month were computed by averaging over all depths within each year (n = 60). Standard error denoted by vertical bar.

Stylodrilus heringianus 15m

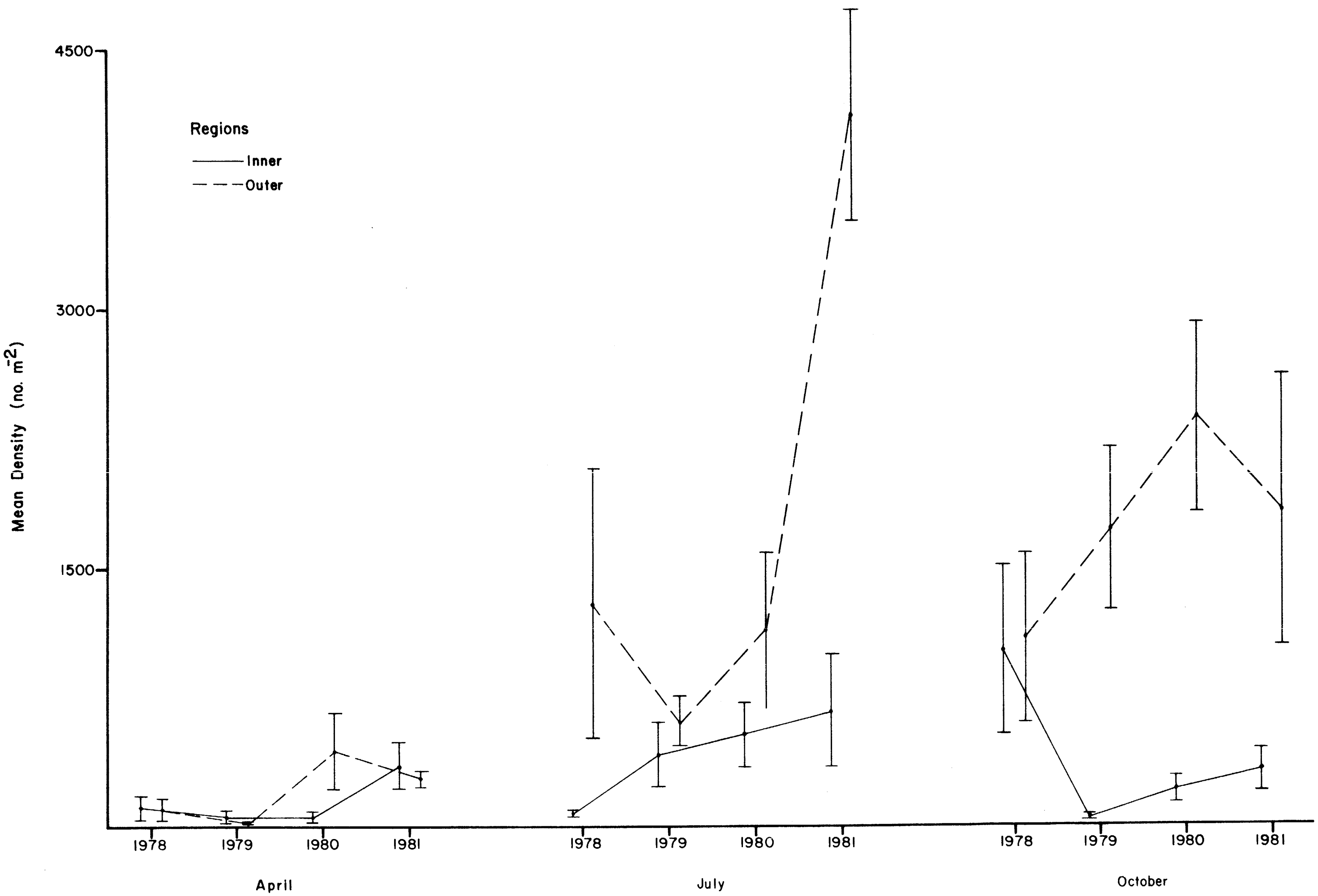

Fig. 19. Inner and outer regional mean densities (number m^{-2}) of S. heringianus collected in April, July, and October 1978 through 1981 from eastern Lake Michigan at 15 m near the J. H. Campbell Plant. Standard error denoted by vertical bar (n = 6). Inner region corresponds to treatment area near present thermal discharge. Outer region corresponds to reference area.

Table 12. Analysis of variance results for densities [$\log_{10}(x+1)$] of <u>Stylodrilus heringianus</u> occurring at 15 m from 1978-1981 near the J.H. Campbell Plant, eastern Lake Michigan [NS = no significance ($p > 0.05$), * = $0.01 < p \leq 0.05$, ** = $0.001 < p \leq 0.01$, *** = $p \leq 0.001$].

Parameter	Sum of squares	Degrees of freedom	Mean square	F-ratio	Signif.
Region(R)	12.17	1	12.17	3.58	NS
Month(M)	27.08	2	13.54	13.41	*
Year(Y)	23.99	3	8.00	9.09	***
RM	1.08	2	0.54	0.24	NS
RY	10.20	3	3.40	3.86	**
MY	6.07	6	1.01	1.15	NS
RMY	13.56	6	2.26	2.57	*
Error	105.24	120	0.88		

that from 1978 to 1981 there was no measurable plant effect associated with the *S. heringianus* population occurring at 15 m near the Campbell Plant.

Gastropoda--

The mean number of gastropods encountered during 1981 (156 m^{-2}) was considerably greater than a similar estimate from the previous 3 yr (56 m^{-2}). However, regional gastropod increases were fairly similar, with a 33% increase in the inner region and a 54% increase in the outer region. Very few gastropods were collected at depths less than 9 m. Greatest gastropod densities were observed at 12 and 15 m (Fig. 20). Monthly gastropod densities tended to increase from April through October, but were quite variable from year-to-year (Fig. 21). During 1981, the higher gastropod abundances observed at 12 and 15 m and during July and October did not greatly exceed the previous range of values. As noted during preoperational years, and as was the case during 1981, there were very few regional density differences among the gastropods encountered at 9 to 15 m (Fig. 22, Appendix 4).

Based on the gastropod ANOVA, regional and month main effects were not significant, while main effects of depth and year were significant (Table 13). The ANOVA had an R value of 4.46 (Table 7). As the R' value was 1.78, no detectable plant effect was associated with gastropods occurring at 9 to 15 m from 1978 to 1981 near the Campbell Plant.

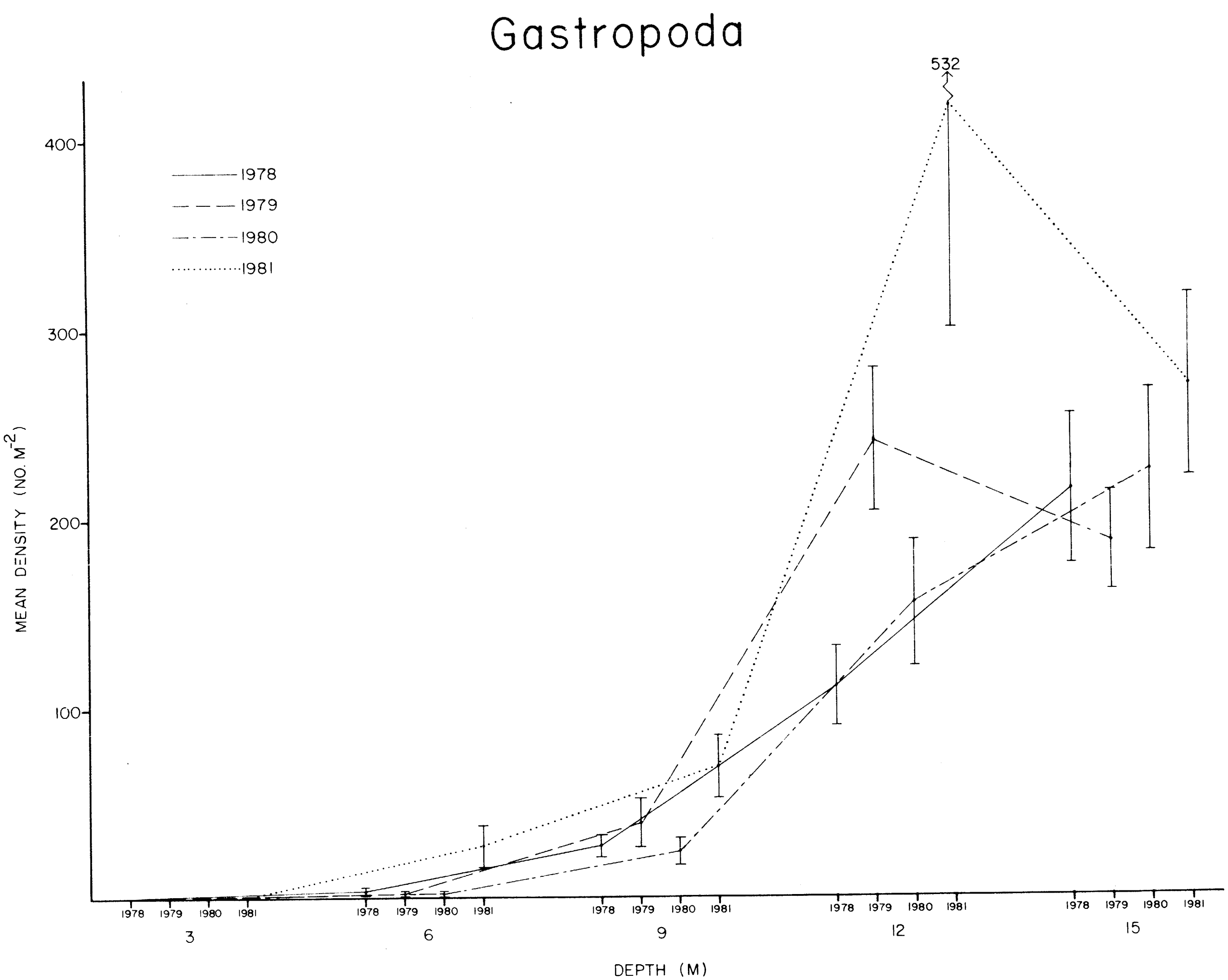

Fig. 20. Mean density (number m^{-2}) of gastropods collected at 3-15 m from 1978 through 1981 in eastern Lake Michigan near the J. H. Campbell Plant. Density estimates at each depth were computed by averaging over all months within each year (n = 36). Standard error denoted by vertical bar.

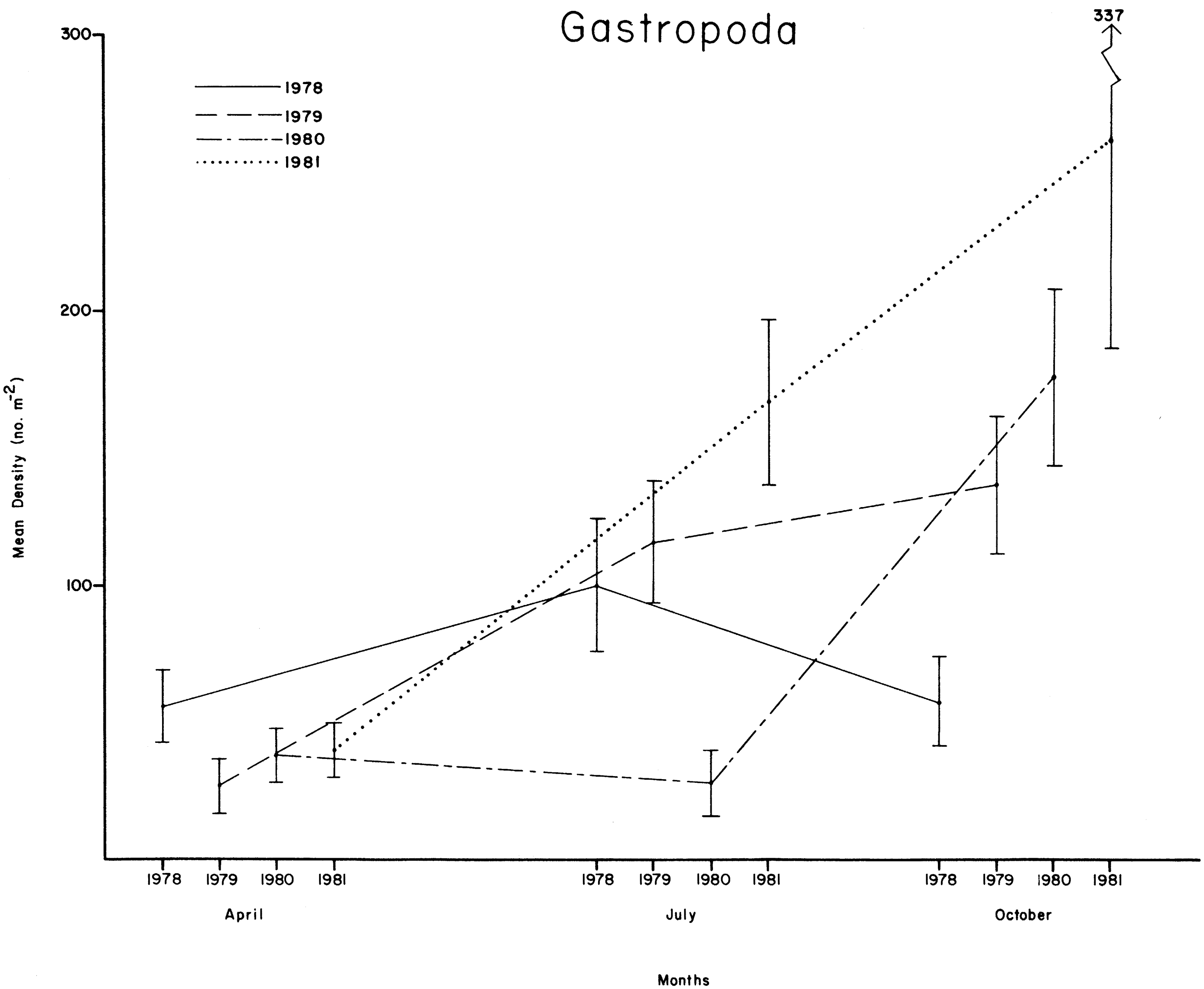

Fig. 21. Mean density (number m^{-2}) of gastropods collected during April, July, and October 1978 through 1981 in eastern Lake Michigan near the J. H. Campbell Plant. Density estimates for each month were computed by averaging over all depths within each year (n = 60). Standard error denoted by vertical bar.

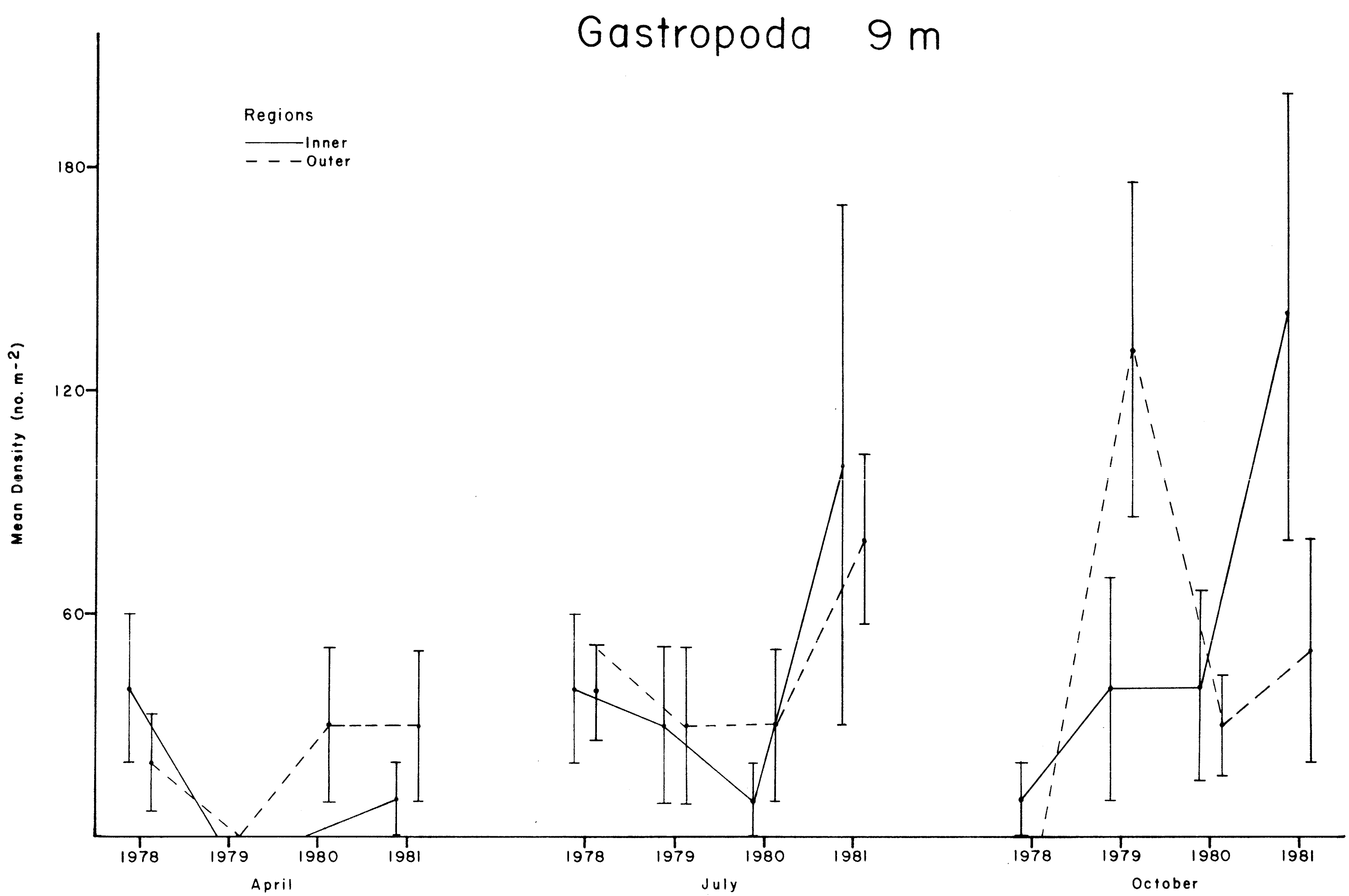

Fig. 22. Inner and outer regional mean densities (number m^{-2}) of gastropods collected in April, July, and October 1978 through 1981 from eastern Lake Michigan at 9-15 m near the J. H. Campbell Plant. Standard error denoted by vertical bar (n = 6). Inner region corresponds to treatment area near present thermal discharge. Outer region corresponds to reference area.

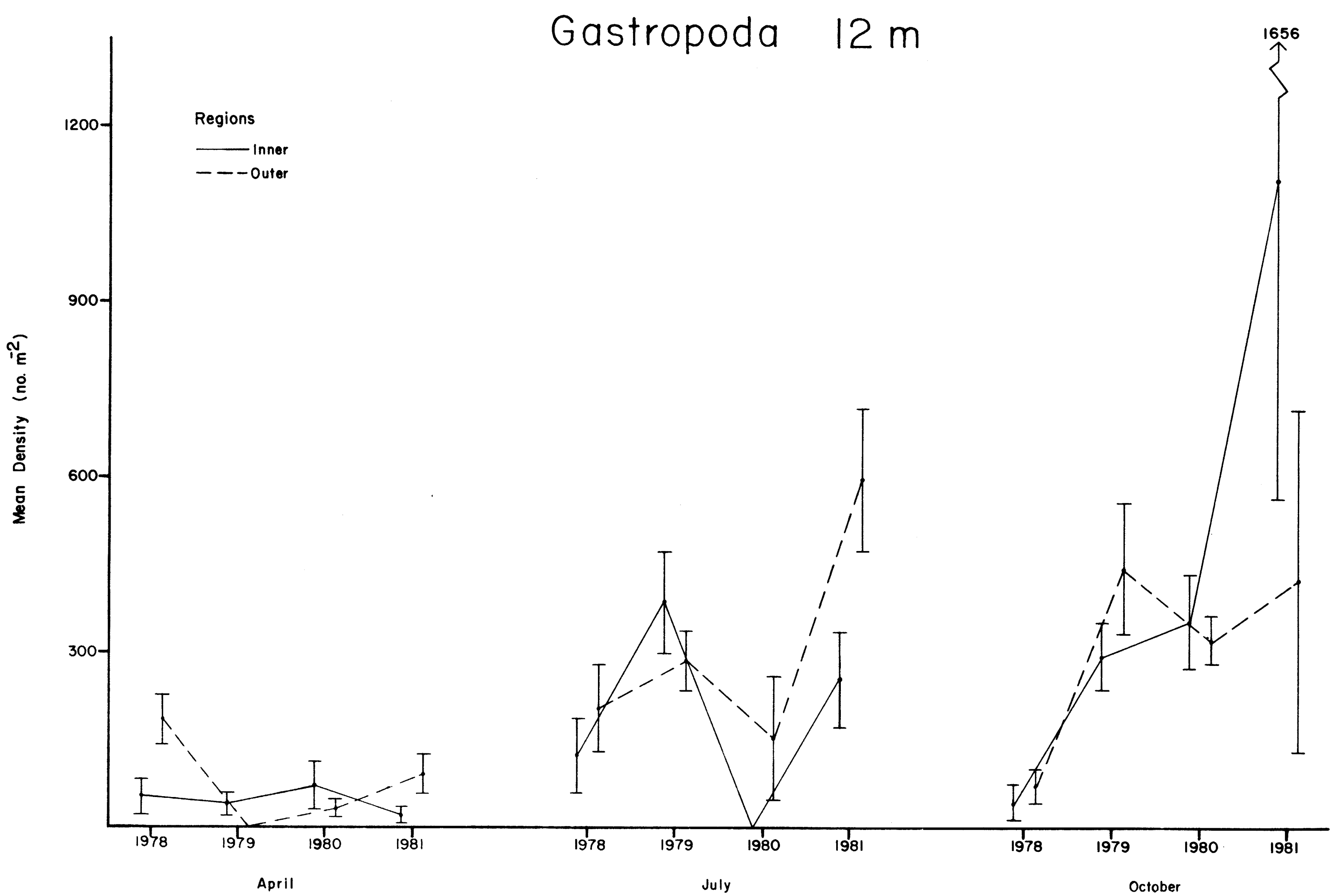

Fig. 22. Continued

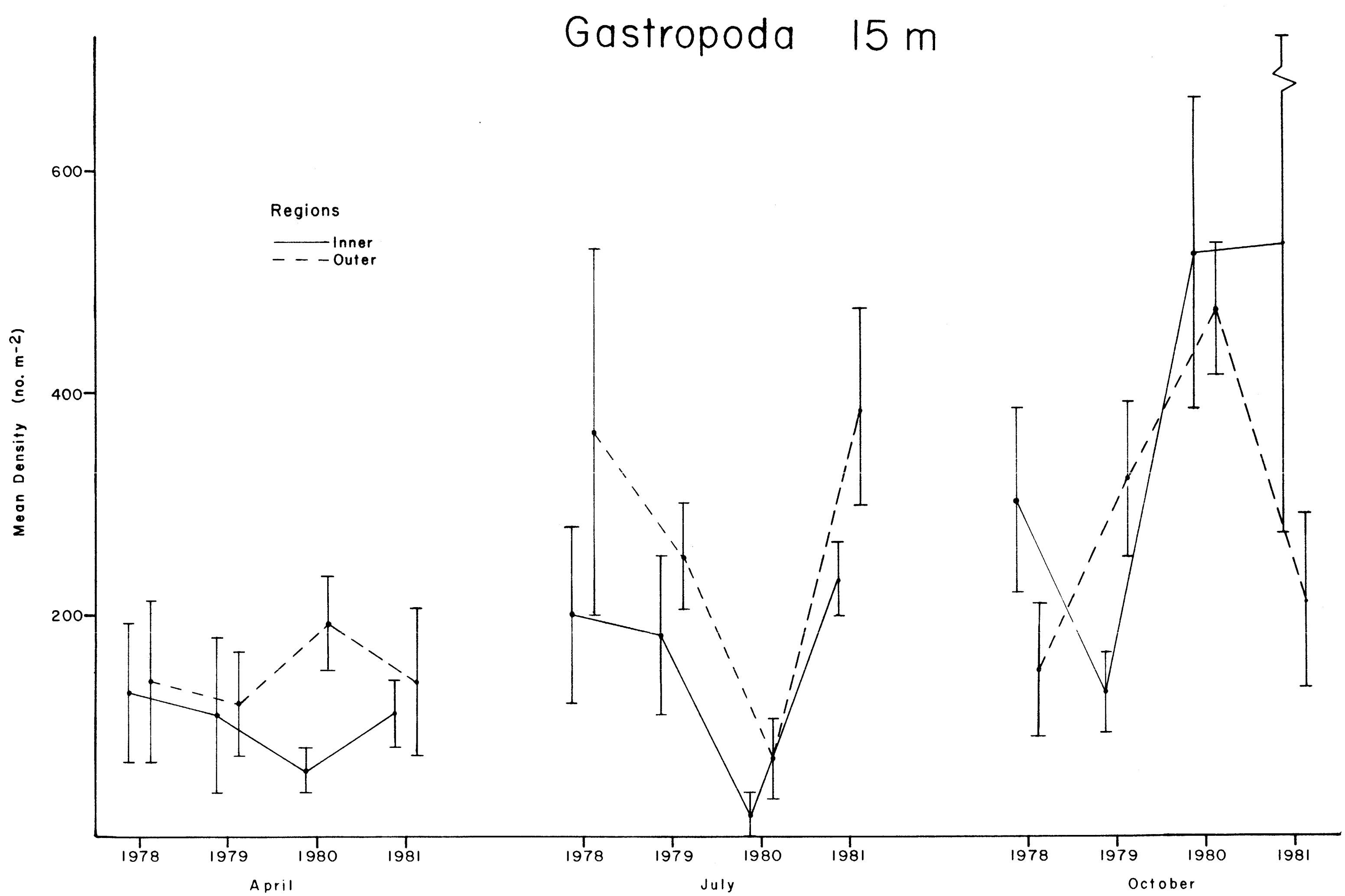

Fig. 22. Continued

Table 13. Analysis of variance results for densities [$\log_{10}(x+1)$] of gastropods occurring at 9-15 m from 1978-1981 near the J.H. Campbell Plant, eastern Lake Michigan [NS = no significance ($p > 0.05$), * = $0.01 < p \leq 0.05$, ** = $0.001 < p \leq 0.01$, *** = $p \leq 0.001$].

Parameter	Sum of squares	Degrees of freedom	Mean square	F-ratio	Signif.
Region(R)	3.92	1	3.92	3.84	NS
Depth(D)	103.99	2	51.99	76.46	***
Month(M)	43.63	2	21.82	2.26	NS
Year(Y)	18.56	3	6.19	8.72	***
RD	0.66	2	0.33	0.18	NS
RM	4.03	2	2.01	1.34	NS
DM	6.56	4	1.64	0.88	NS
RY	3.07	3	1.02	1.44	NS
DY	4.09	6	0.68	0.96	NS
MY	57.87	6	9.64	13.58	***
RDM	0.10	4	0.02	0.04	NS
RDY	11.24	6	1.87	2.63	*
RMY	9.02	6	1.50	2.11	*
DMY	22.33	12	1.86	2.62	**
RDMY	6.96	12	0.58	0.82	NS
Error	254.34	360	0.71		

Pisidium--

Although average *Pisidium* abundance was slightly higher during 1981 (536 m^{-2}) than during the 1978 to 1980 period (387 m^{-2}), proportionate increases were similar in both the inner (17%) and outer (15%) regions. Based on the range of 1978 to 1980 densities, pisidia abundances observed during 1981 at each depth (Fig. 23) and during each month (Fig. 24) were very similar within respective depths and months. In addition, with the exception of 9-m July pisidia densities within which outer region densities exceeded inner region densities, no consistent regional density trends were evident (Fig. 25, Appendix 4).

The *Pisidium* ANOVA was based on the 9- to 15-m population densities, since few pisidia occurred at depths shallower than 9 m. The main effect due to depth was highly significant as pisidia abundance steadily increased with depth (Table 14). While the year main effect was also highly significant, neither month nor regional main effects were significant. Across months there tended to be a slight increase in average density from April to October, but annual variability associated with monthly densities was quite high, thereby obscuring a definitive trend. As the R value (3.07) was considerably greater than the R' value (1.87) (Table 7), we concluded there was no detectable plant effect on the pisidia population at 9 to 15 m during 1978 to 1981 near the Campbell Plant.

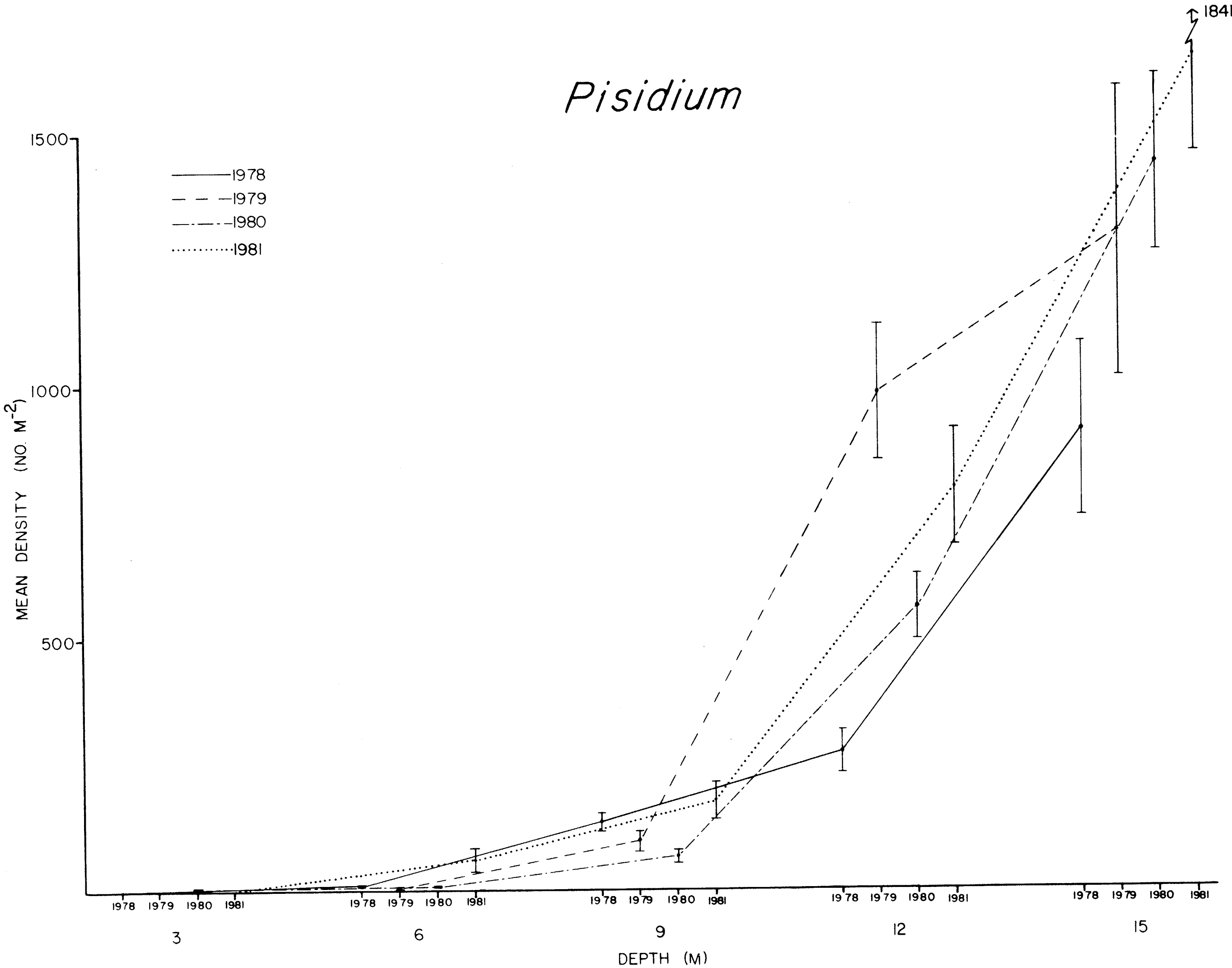

Fig. 23. Mean density (number m^{-2}) of <u>Pisidium</u> collected at 3-15 m from 1978 through 1981 in eastern Lake Michigan near the J. H. Campbell Plant. Density estimates at each depth were computed by averaging over all months within each year (n = 36). Standard error denoted by vertical bar.

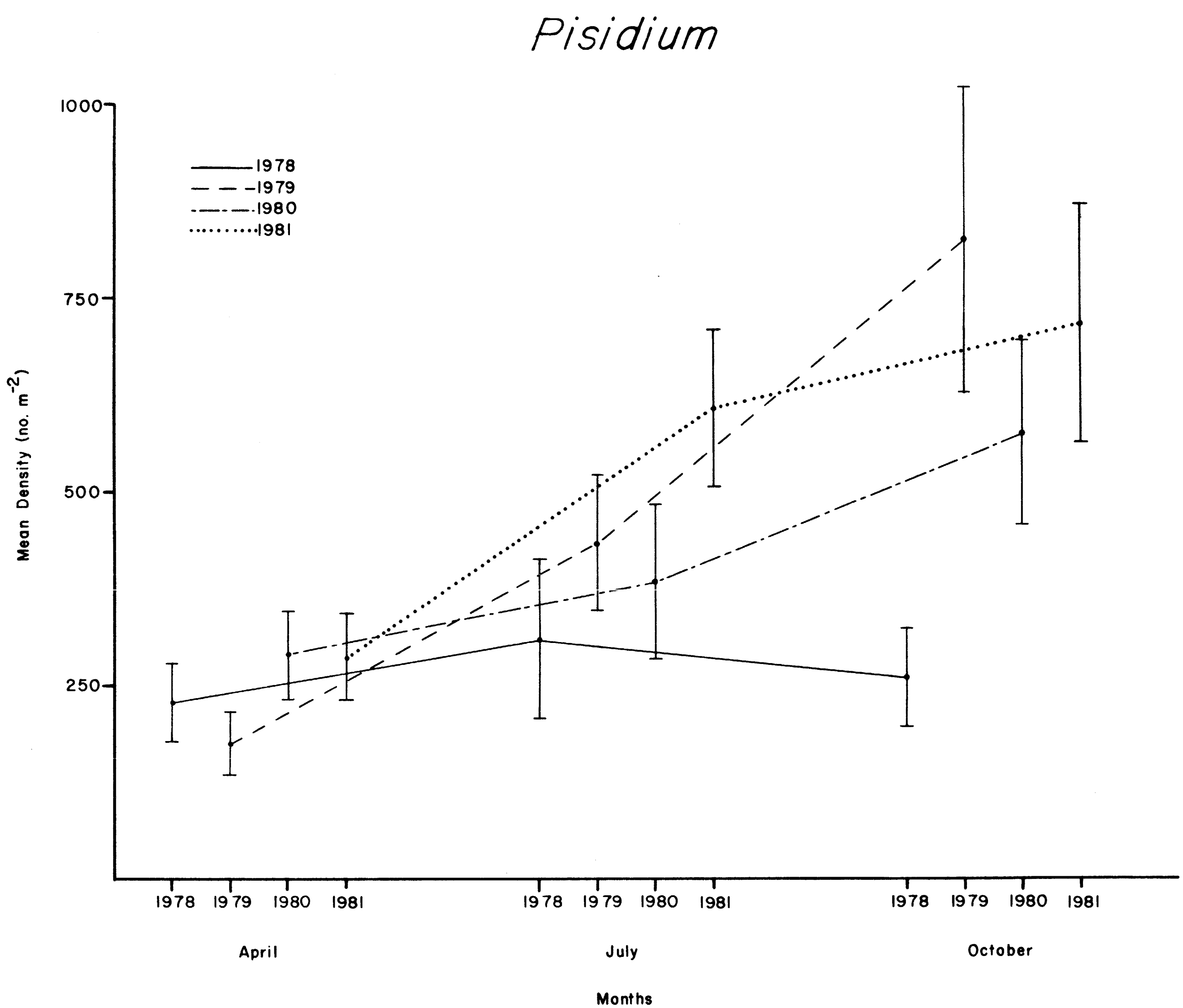

Fig. 24. Mean density (number m^{-2}) of *Pisidium* collected during April, July, and October 1978 through 1981 in eastern Lake Michigan near the J. H. Campbell Plant. Density estimates for each month were computed by averaging over all depths within each year (n = 60). Standard error denoted by vertical bar.

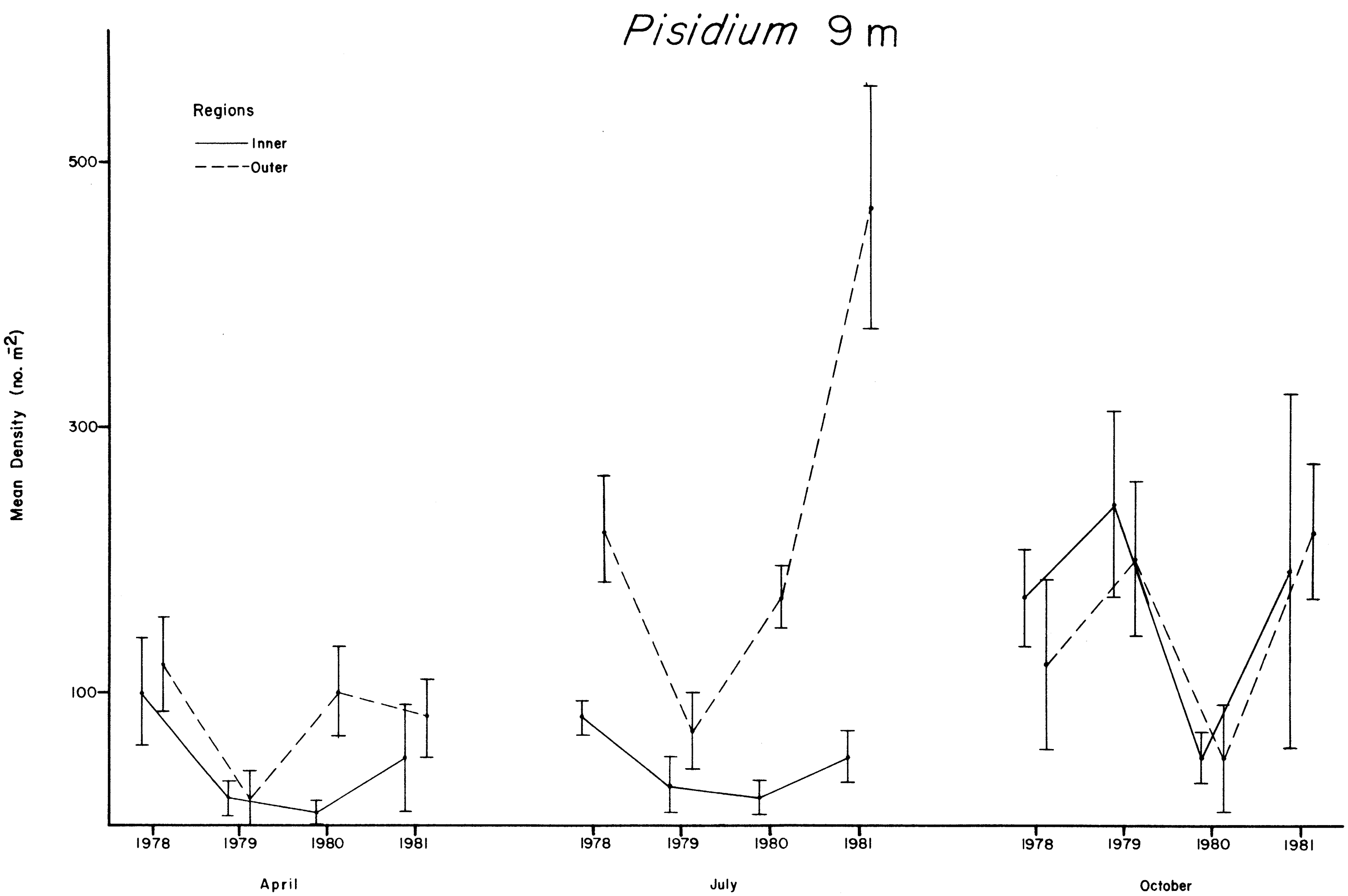

Fig. 25. Inner and outer regional mean densities (number m^{-2}) of *Pisidium* collected in April, July, and October 1978 through 1981 from eastern Lake Michigan at 9-15 m near the J. H. Campbell Plant. Standard error denoted by vertical bar (n = 6). Inner region corresponds to treatment area near present thermal discharge. Outer region corresponds to reference area.

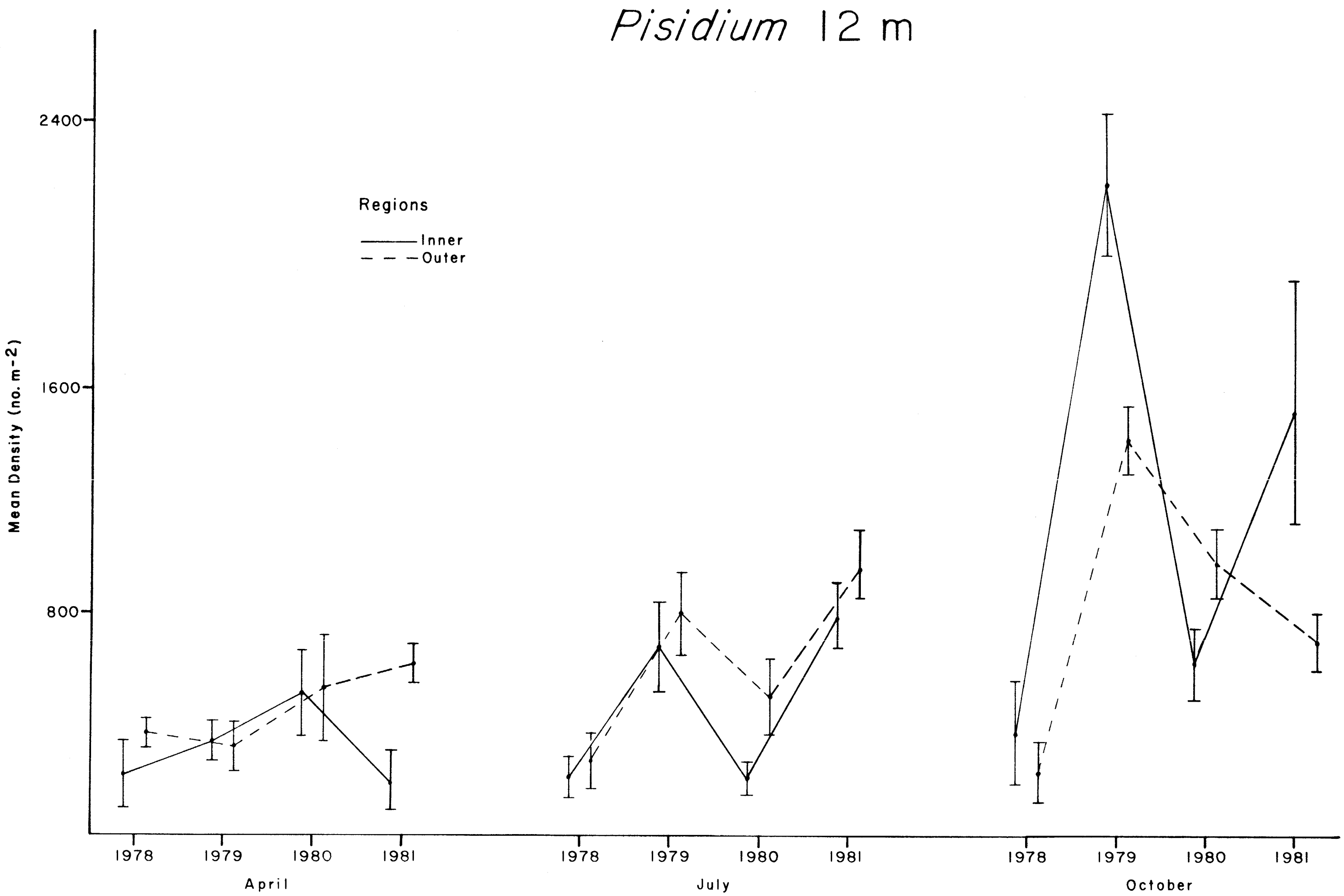

Fig. 25. Continued

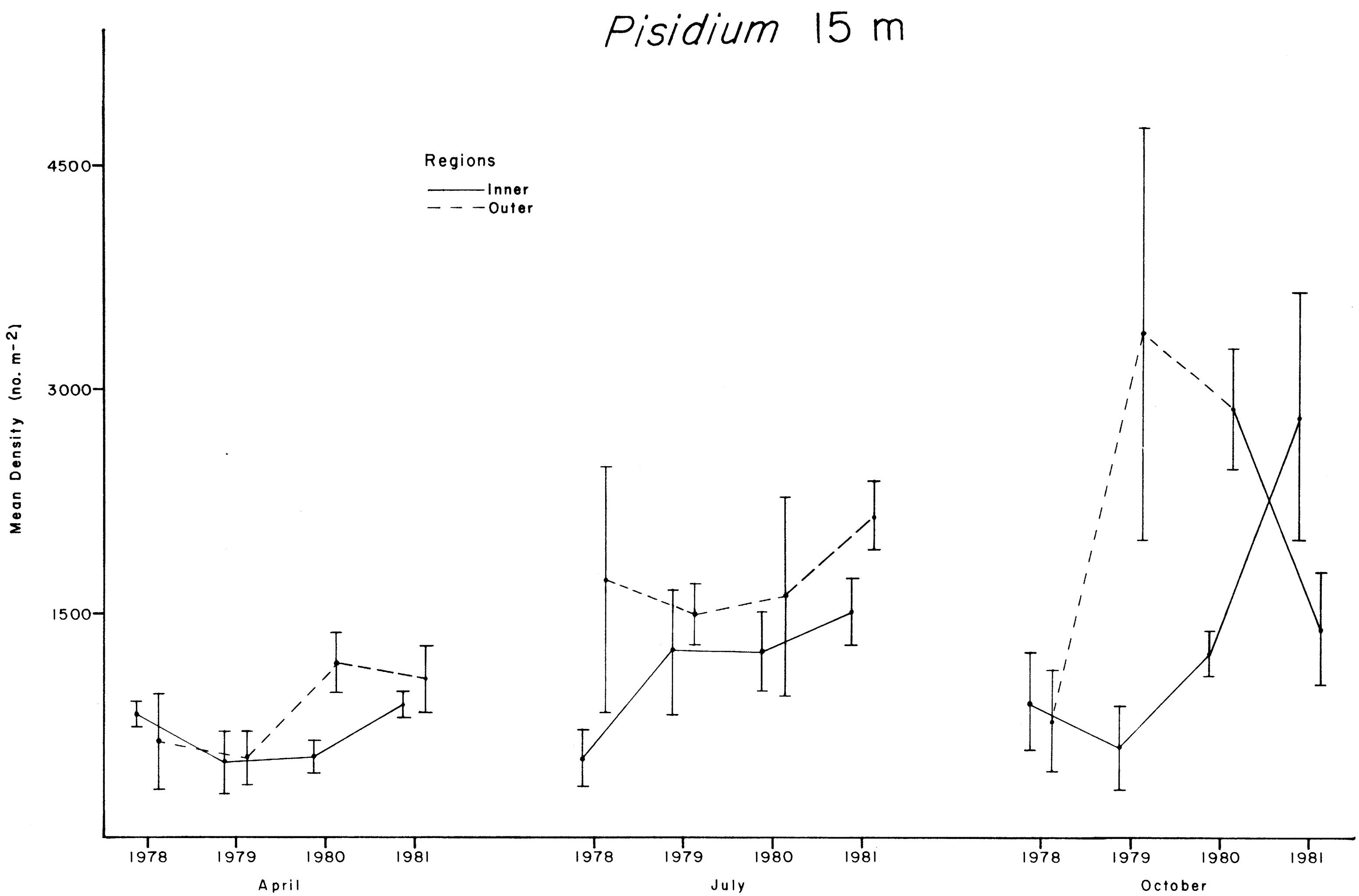

Fig. 25. Continued

Table 14. Analysis of variance results for densities [$\log_{10}(x+1)$] of *Pisidium* occurring at 9-15 m from 1978-1981 near the J.H. Campbell Plant, eastern Lake Michigan [NS = no significance ($p > 0.05$), * = $0.01 < p \leq 0.05$, ** = $0.001 < p \leq 0.01$, *** = $p \leq 0.001$].

Parameter	Sum of squares	Degrees of freedom	Mean square	F-ratio	Signif.
Region(R)	5.11	1	5.11	3.45	NS
Depth(D)	158.98	2	79.49	15.74	**
Month(M)	17.79	2	8.90	3.46	NS
Year(Y)	7.91	3	2.64	5.39	**
RD	3.58	2	1.79	2.18	NS
RM	4.10	2	2.05	3.15	NS
DM	2.30	4	0.58	0.62	NS
RY	4.45	3	1.48	3.02	*
DY	30.30	6	5.05	10.31	***
MY	15.44	6	2.57	5.24	***
RDM	6.53	4	1.63	2.20	NS
RDY	4.91	6	0.82	1.67	NS
RMY	3.89	6	0.65	1.33	NS
DMY	11.19	12	0.93	1.90	*
RDMY	8.88	12	0.74	1.51	NS
Error	177.64	360	0.49		

Turbellaria--

Of the 10 taxonomic groups encountered, turbellarian densities were the most unpredictable from year-to-year. Neither average densities within depths (Fig. 26) nor months (Fig. 27) were predictable on an annual basis. During 1981, the proportionate increase in turbellarian density, when compared with that of the previous 3 yr, was considerably higher in the outer (72%) than in the inner (27%) region. Overall, turbellarian density increased 81% during 1981 when compared with the 3-yr preoperational average. Examination of regional density trends at each depth indicated considerable annual variability at all depths, but only sporadic regional density differences at the 6- to 15-m depths (Fig. 28, Appendix 1). At 3 m, outer region turbellarian densities generally exceeded inner region abundances, but nonetheless mean densities in both regions were highly variable and unpredictable from year-to-year.

All main effects except month were significant based on the ANOVA of turbellarian densities occurring at 3 to 15 m (Table 15). Year was the most highly significant of the main effects, followed by depth and region. Significance of the region main effect indicated the outer region density was greater than the inner region density. This regional density difference was likely attributable to the large and highly variable turbellarian abundance associated with the 3-m depth regime. With the ANOVA's sensitivity determined to be R = 2.49 (Table 7), disparate regional density trends

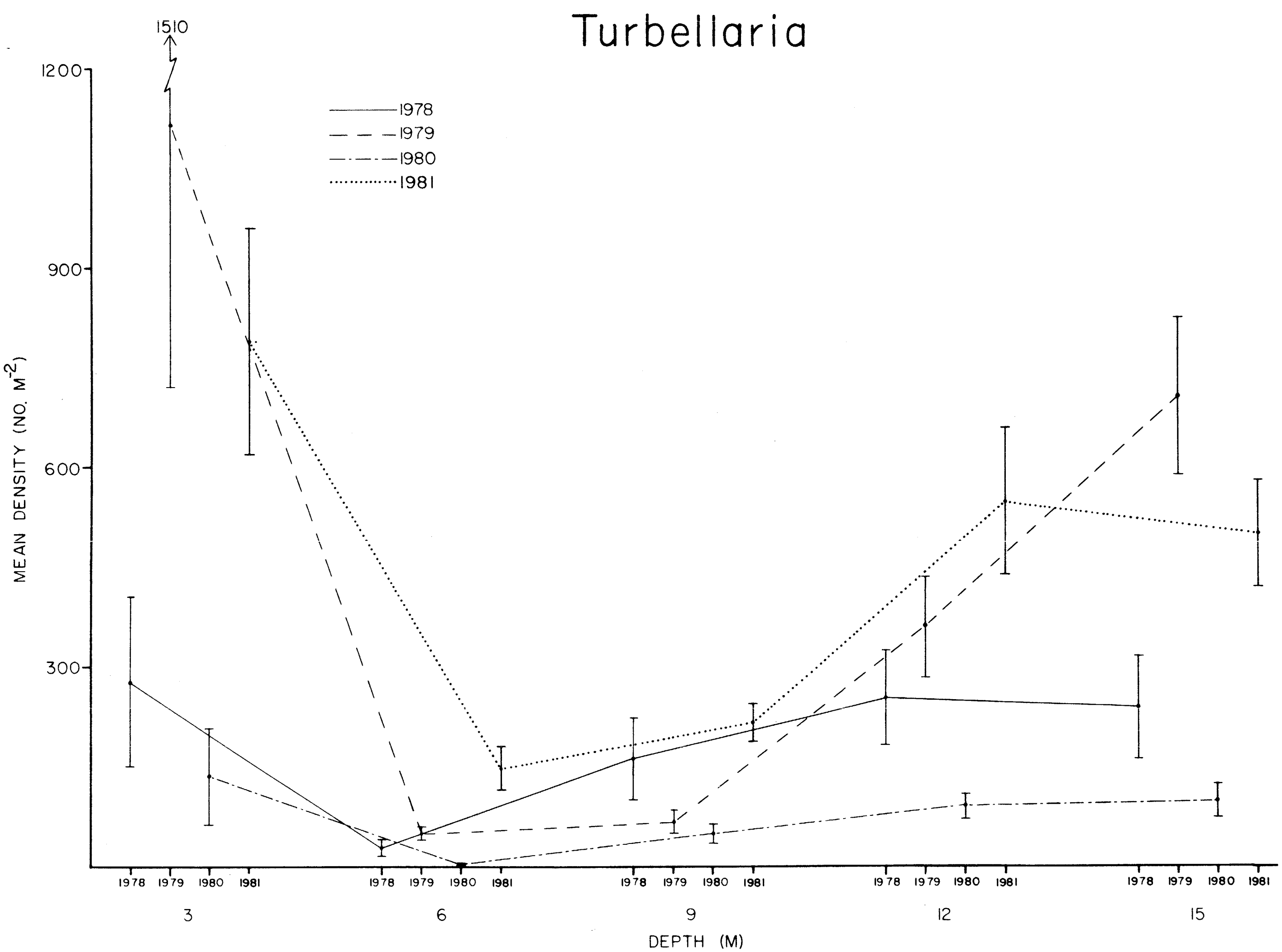

Fig. 26. Mean density (number m^{-2}) of turbellarians collected at 3-15 m from 1978 through 1981 in eastern Lake Michigan near the J. H. Campbell Plant. Density estimates at each depth were computed by averaging over all months within each year (n = 36). Standard error denoted by vertical bar.

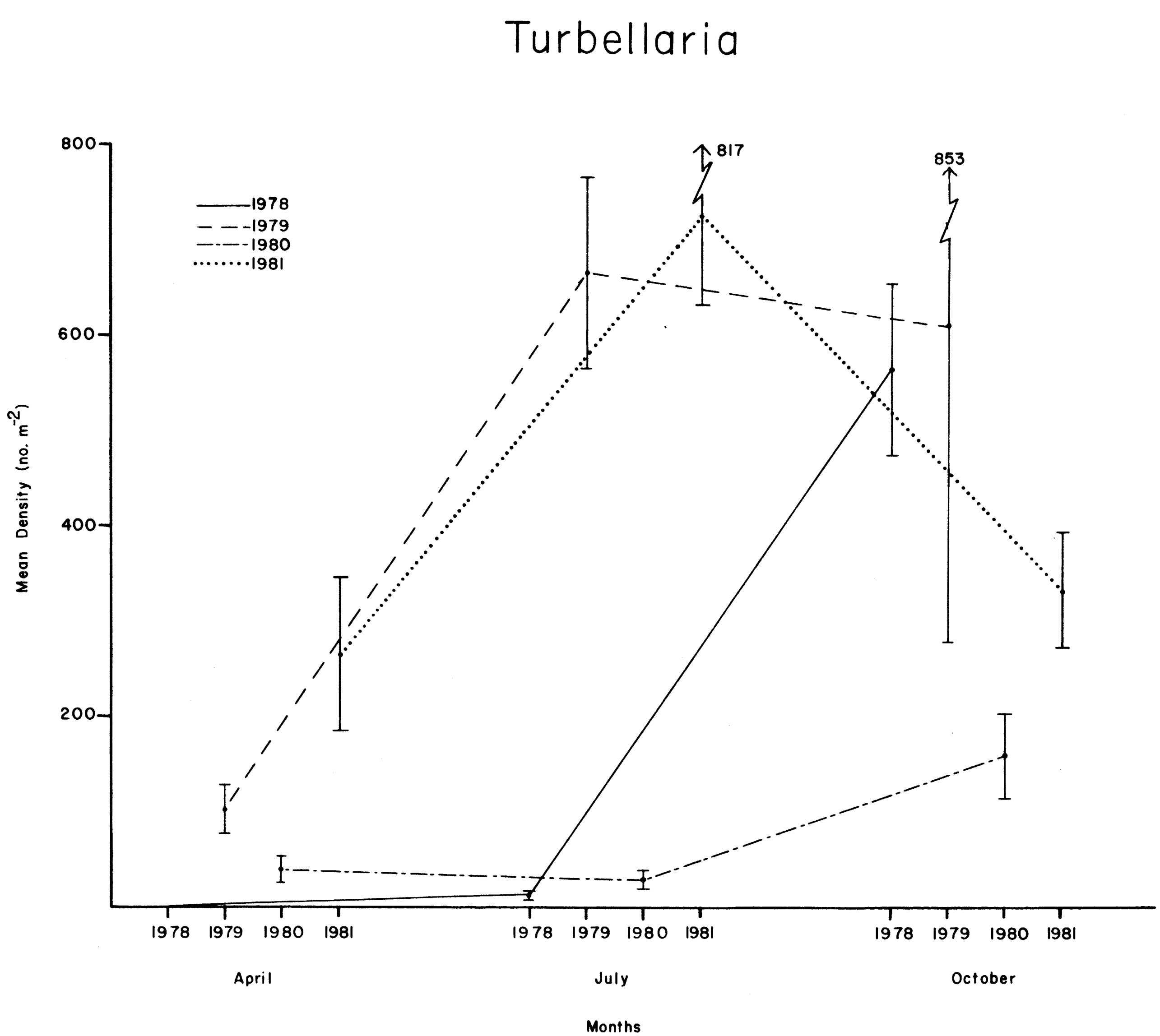

Fig. 27. Mean density (number m^{-2}) of turbellarians collected during April, July, and October 1978 through 1981 in eastern Lake Michigan near the J. H. Campbell Plant. Density estimates for each month were computed by averaging over all depths within each year (n = 60). Standard error denoted by vertical bar.

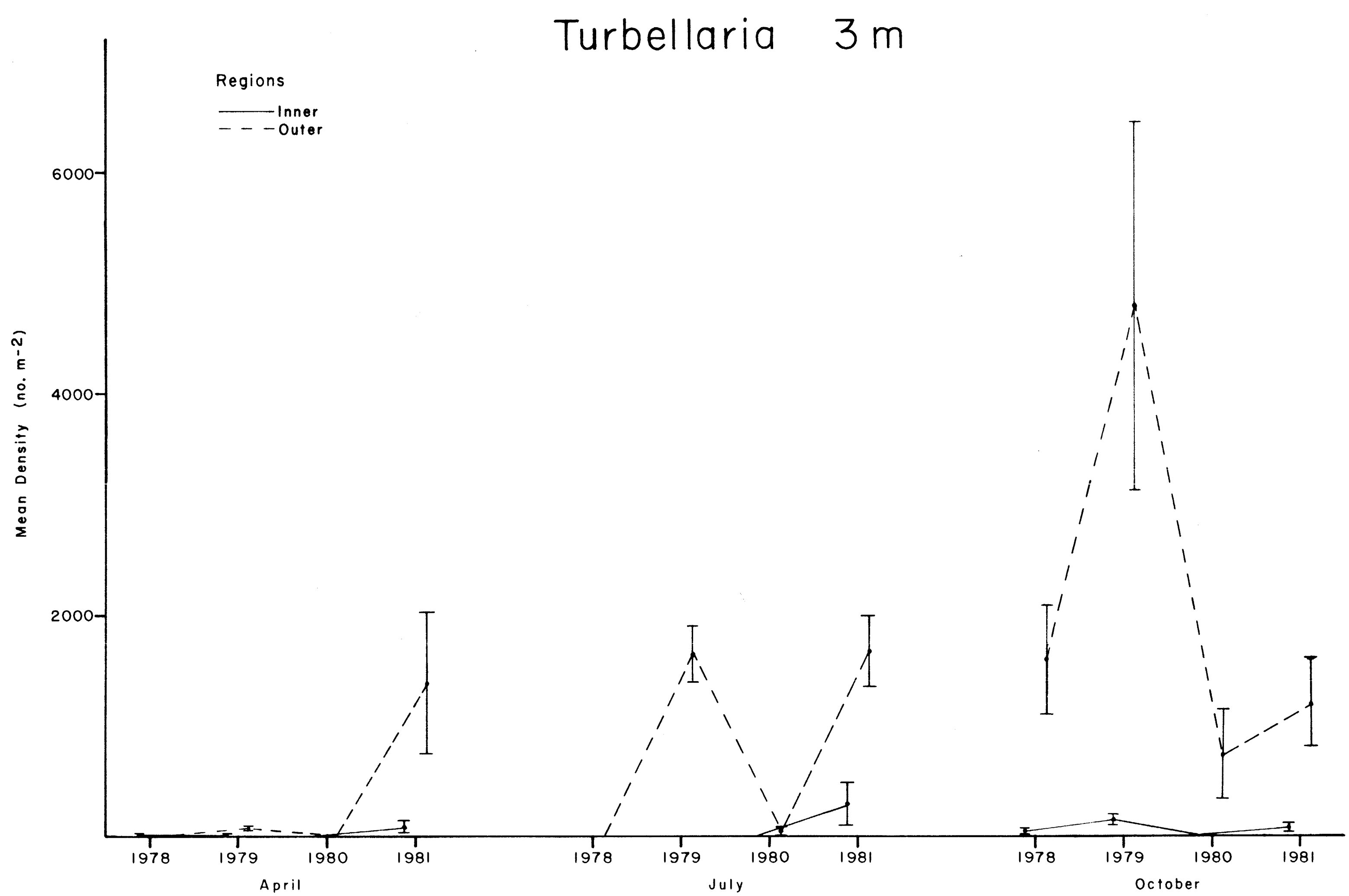

Fig. 28. Inner and outer regional mean densities (number m^{-2}) of turbellarians collected in April, July, and October 1978 through 1981 from eastern Lake Michigan at 3-15 m near the J. H. Campbell Plant. Standard error denoted by vertical bar (n = 6). Inner region corresponds to treatment area near present thermal discharge. Outer region corresponds to reference area.

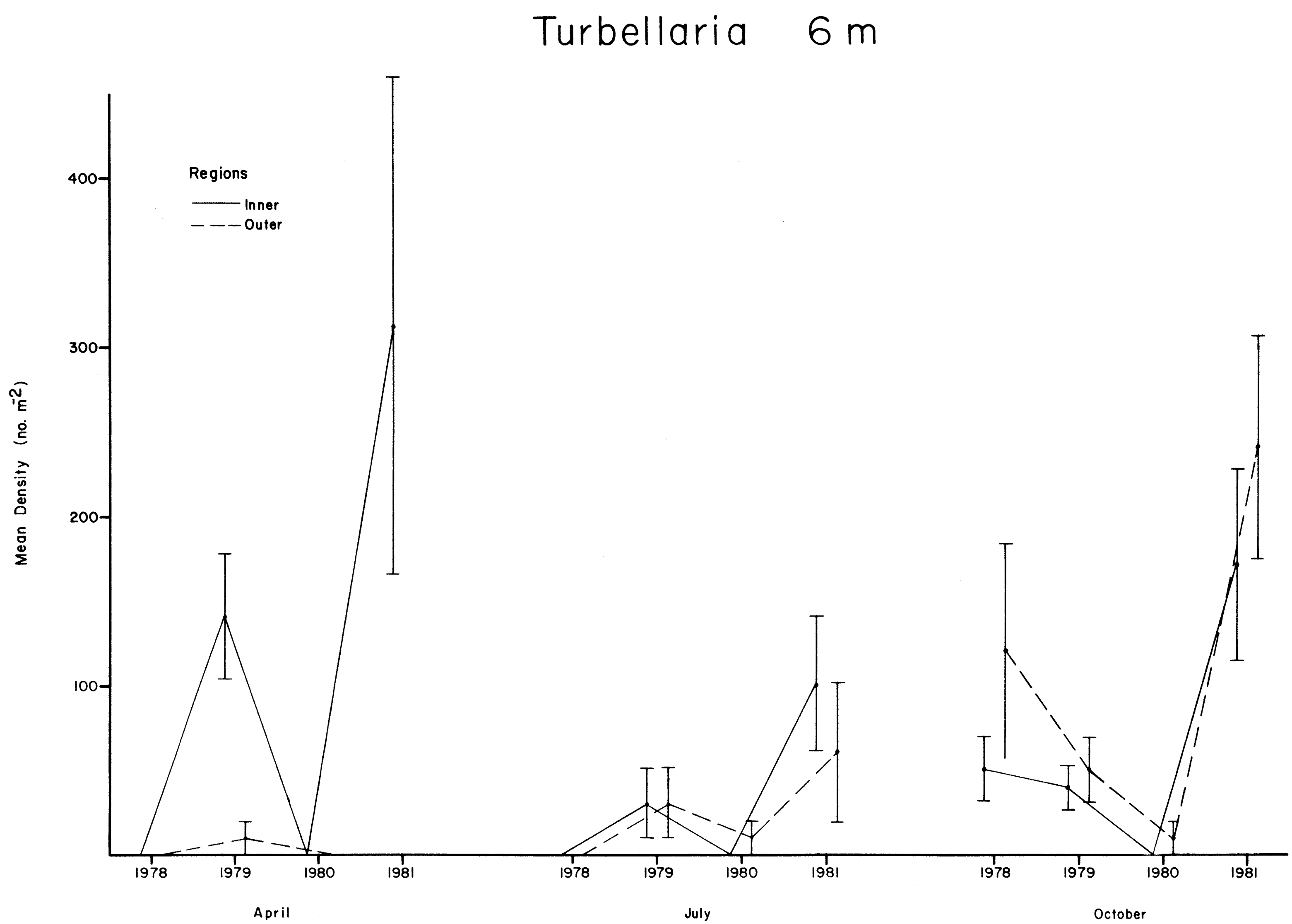

Fig. 28. Continued

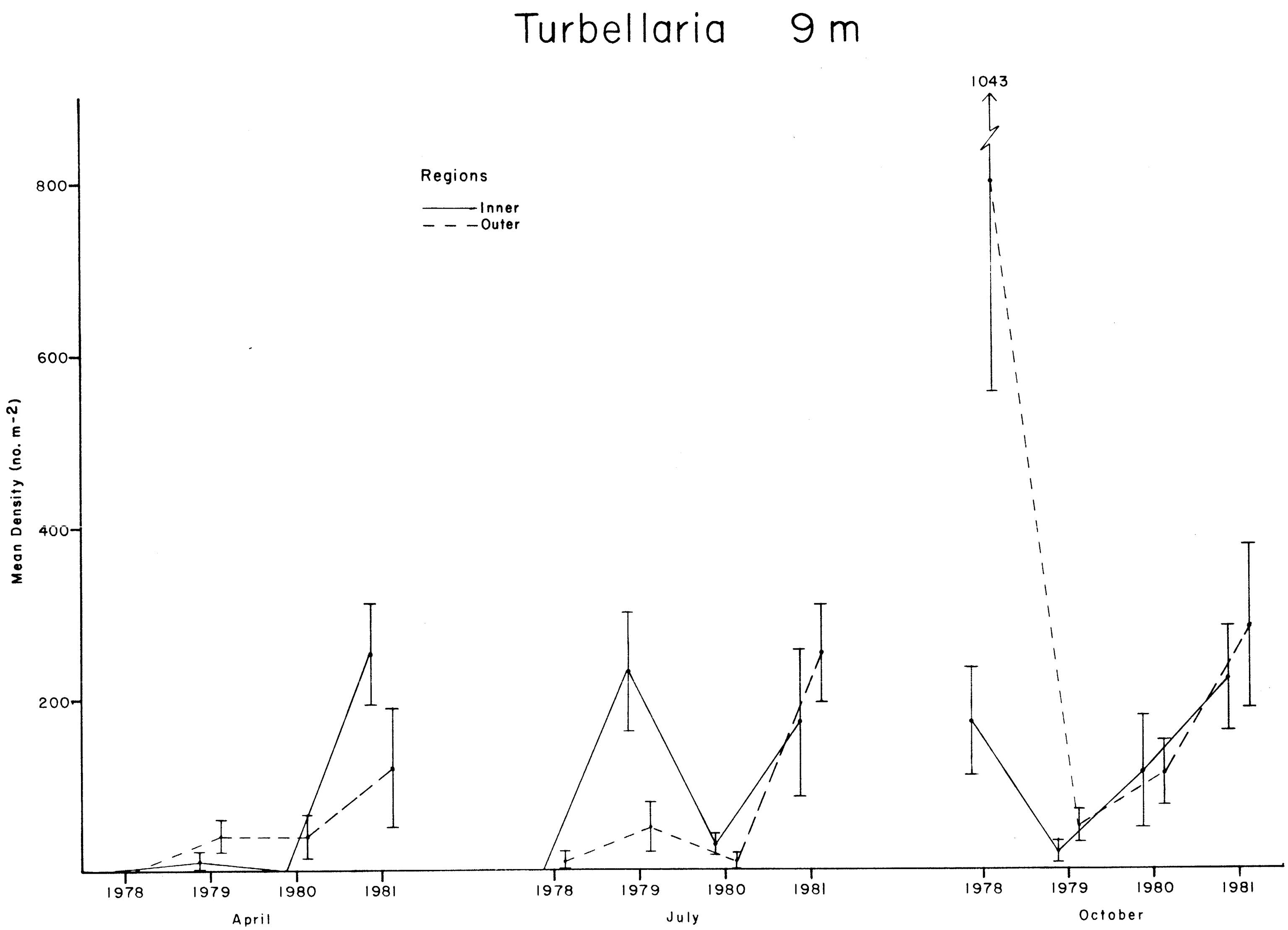

Fig. 28. Continued

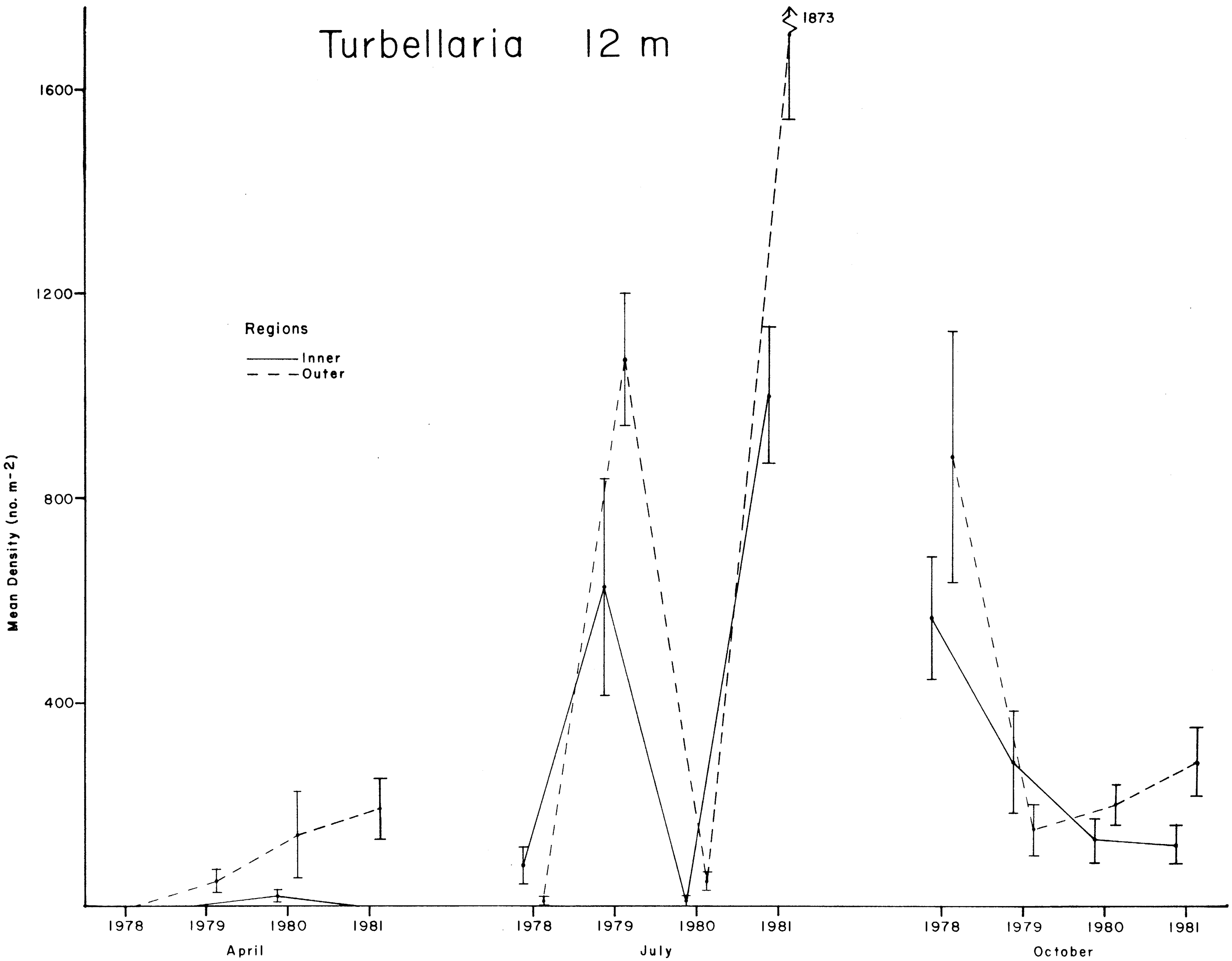

Fig. 28. Continued

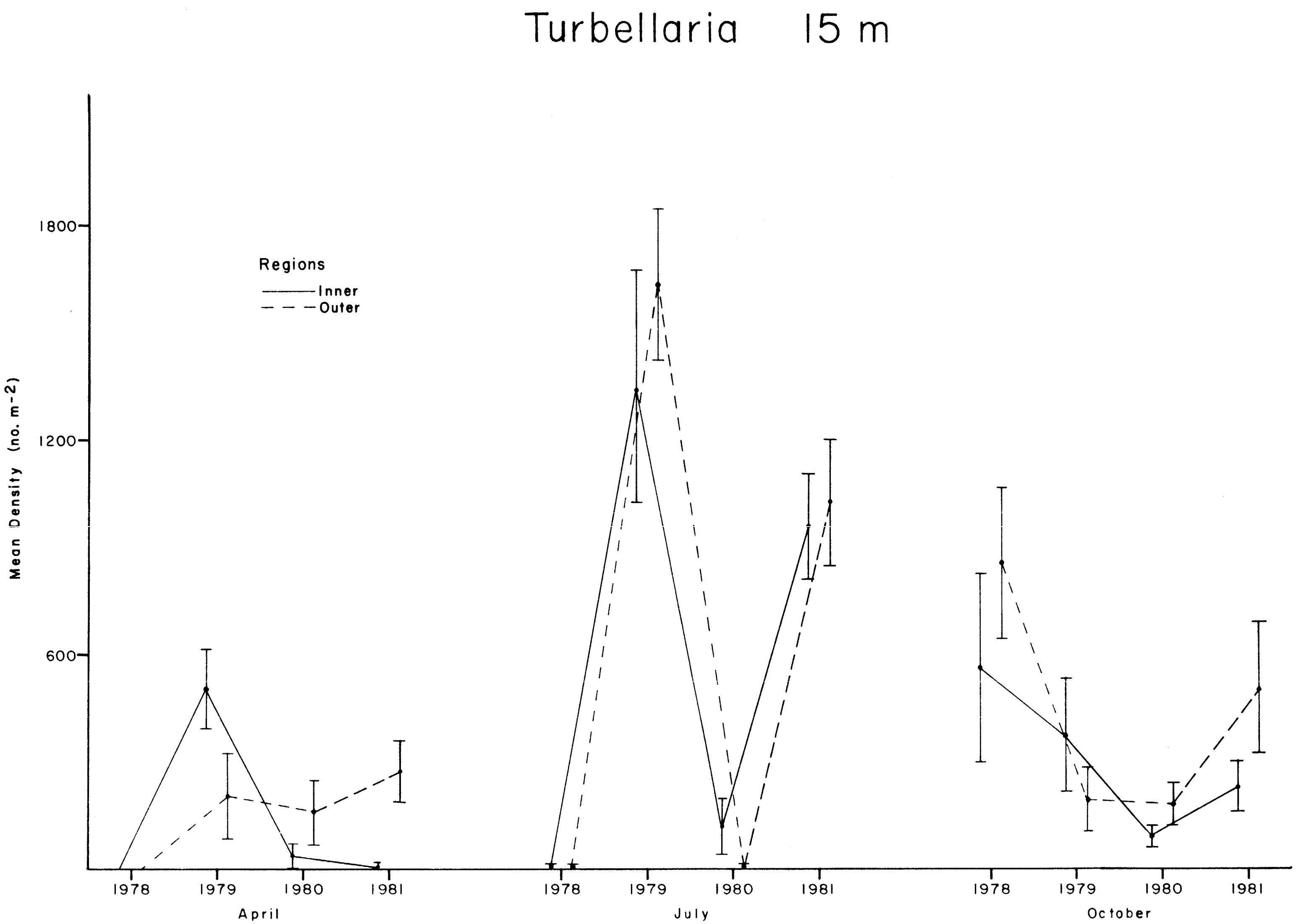

Fig. 28. Continued

Table 15. Analysis of variance results for densities [$\log_{10}(x+1)$] of turbellarians occurring at 3-15 m from 1978-1981 near the J.H. Campbell Plant, eastern Lake Michigan [NS = no significance ($p > 0.05$), * = $0.01 < p \leq 0.05$, ** = $0.001 < p \leq 0.01$, *** = $p \leq 0.001$].

Parameter	Sum of squares	Degrees of freedom	Mean square	F-ratio	Signif.
Region(R)	22.95	1	22.95	25.50	*
Depth(D)	69.66	4	17.42	7.00	**
Month(M)	144.00	2	72.00	4.12	NS
Year(Y)	189.54	3	63.18	117.00	***
RD	53.35	4	13.34	4.78	*
RM	9.85	2	4.92	4.73	NS
DM	28.26	8	3.53	1.35	NS
RY	2.70	3	0.90	1.67	NS
DY	29.88	12	2.49	4.61	***
MY	104.75	6	17.46	32.33	***
RDM	19.51	8	2.44	1.10	NS
RDY	33.49	12	2.79	5.17	***
RMY	6.21	6	1.04	1.93	NS
DMY	63.00	24	2.62	4.85	***
RDMY	53.11	24	2.21	4.09	***
Error	325.97	600	0.54		

did not result in cumulative differences among regions during subsequent years. When contrasting before and after operation regional averaged log densities, an R' value of 1.48 indicated no measurable heat effect due to plant operation was attributable to density changes observed among the turbellarian populations occurring at 3 to 15 m during 1978 to 1981 near the Campbell Plant.

Total Benthos--

Average benthic density in 1981 (9,715 m^{-2}) increased 38% from the 1978-1980 mean density (7,061 m^{-2}). Although 1981 benthic densities were generally higher than similar estimates from the previous 3 yr, there was little difference among preoperational average benthic densities observed within each respective depth (Fig. 29) and during each respective month (Fig. 30). During 1981, outer region mean benthic abundance increased 37% compared with only 10% in the inner region, primarily due to increased oligochaete and *Pontoporeia hoyi* abundance in the outer region. Examination of regional density trends indicated only occasional density differences among regions (Fig. 31, Appendix 1), none of which were sustained beyond the particular month within which they were observed.

The ANOVA based on total benthic densities at 3 to 15 m indicated all main effects were highly to very highly significant except a non-significant regional main effect (Table 16). Nearly all higher-order interactions were very highly significant. Subsequent contrasting of before and after operation regional averaged log densities indicated actual population changes were equivalent to R' = 1.37 (Table 7). As the sensitivity of the ANOVA (R = 1.60) was greater than density changes observed, no measurable plant effect was evident for the benthic population occurring at 3 to 15 m in the vicinity of the Campbell Plant from 1978 to 1981.

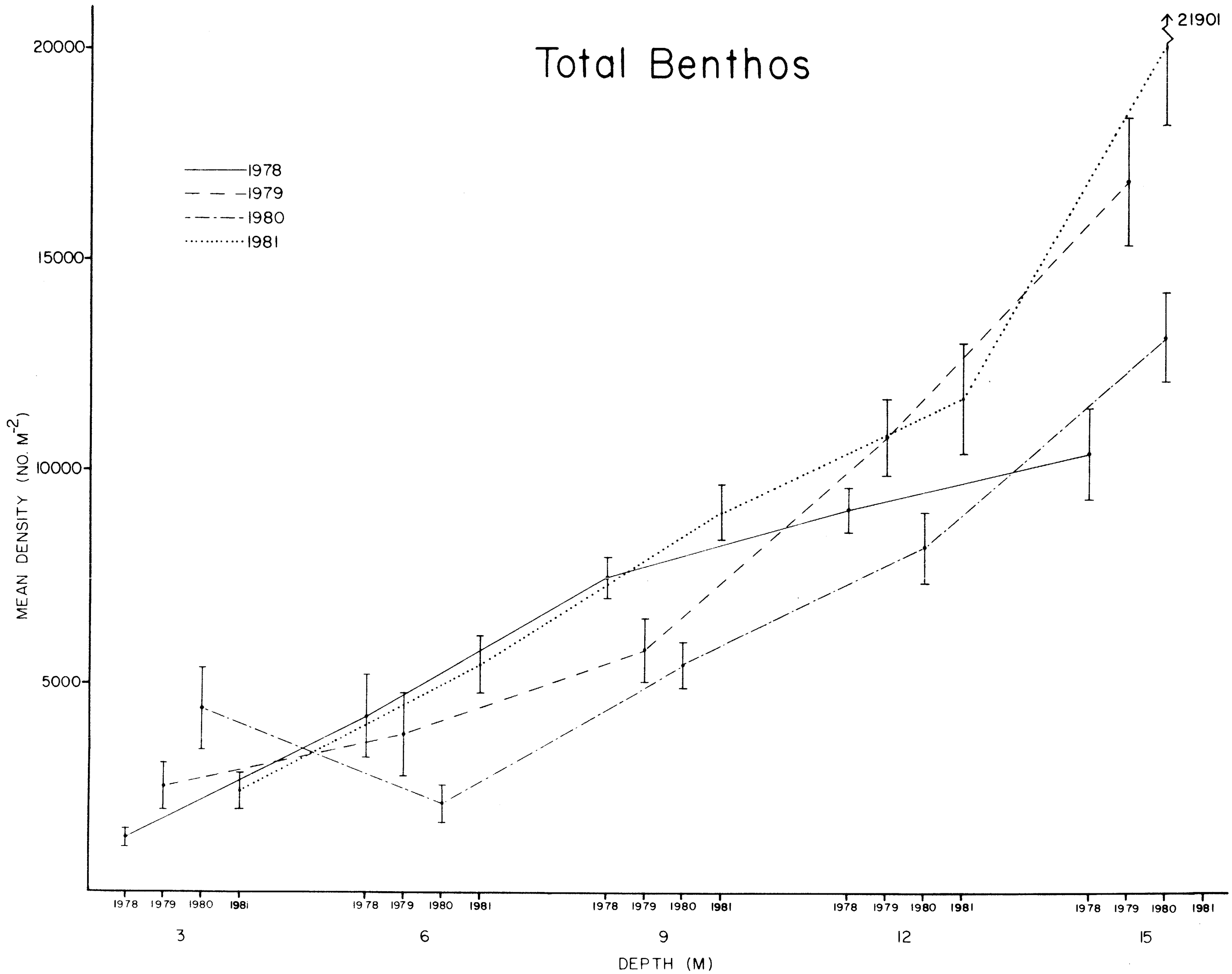

Fig. 29. Mean density (number m^{-2}) of total benthos collected at 3-15 m from 1978 through 1981 in eastern Lake Michigan near the J. H. Campbell Plant. Density estimates at each depth were computed by averaging over all months within each year (n = 36). Standard error denoted by vertical bar.

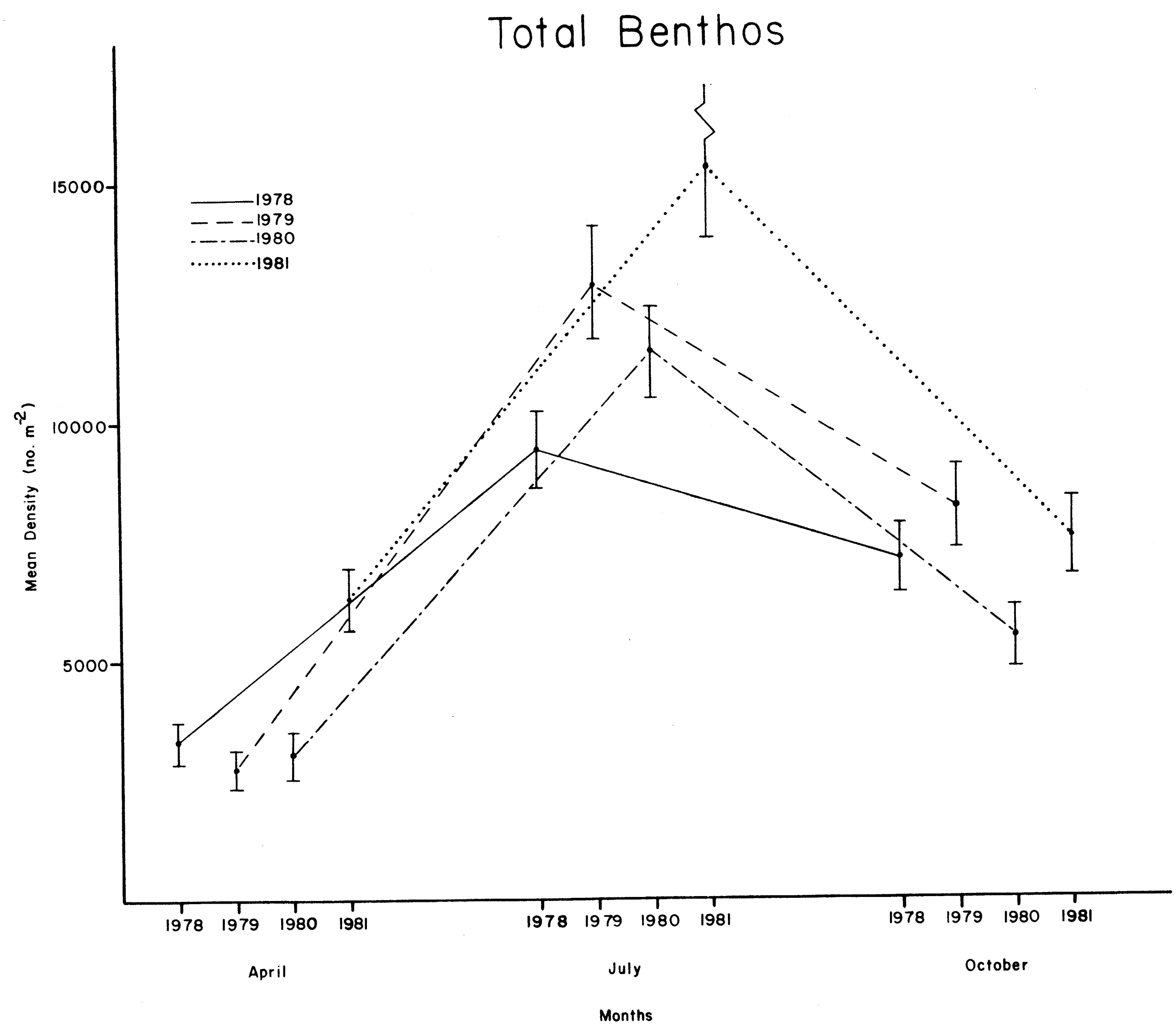

Fig. 30. Mean density (number m^{-2}) of total benthos collected during April, July, and October 1978 through 1981 in eastern Lake Michigan near the J. H. Campbell Plant. Density estimates for each month were computed by averaging over all depths within each year (n = 60). Standard error denoted by vertical bar.

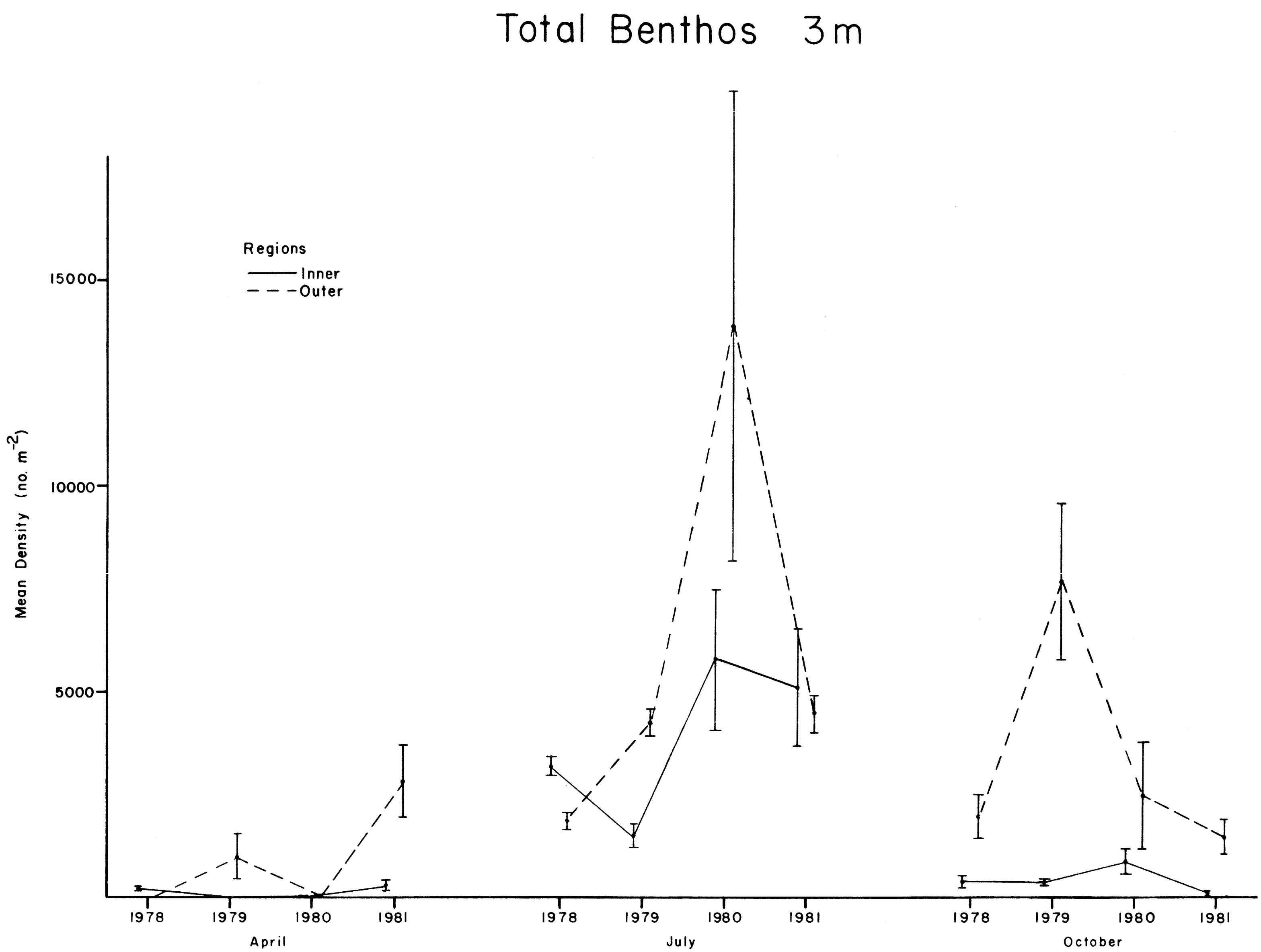

Fig. 31. Inner and outer regional mean densities (number m^{-2}) of total benthos collected in April, July, and October 1978 through 1981 from eastern Lake Michigan at 3-15 m near the J. H. Campbell Plant. Standard error denoted by vertical bar (n = 6). Inner region corresponds to treatment area near present thermal discharge. Outer region corresponds to reference area.

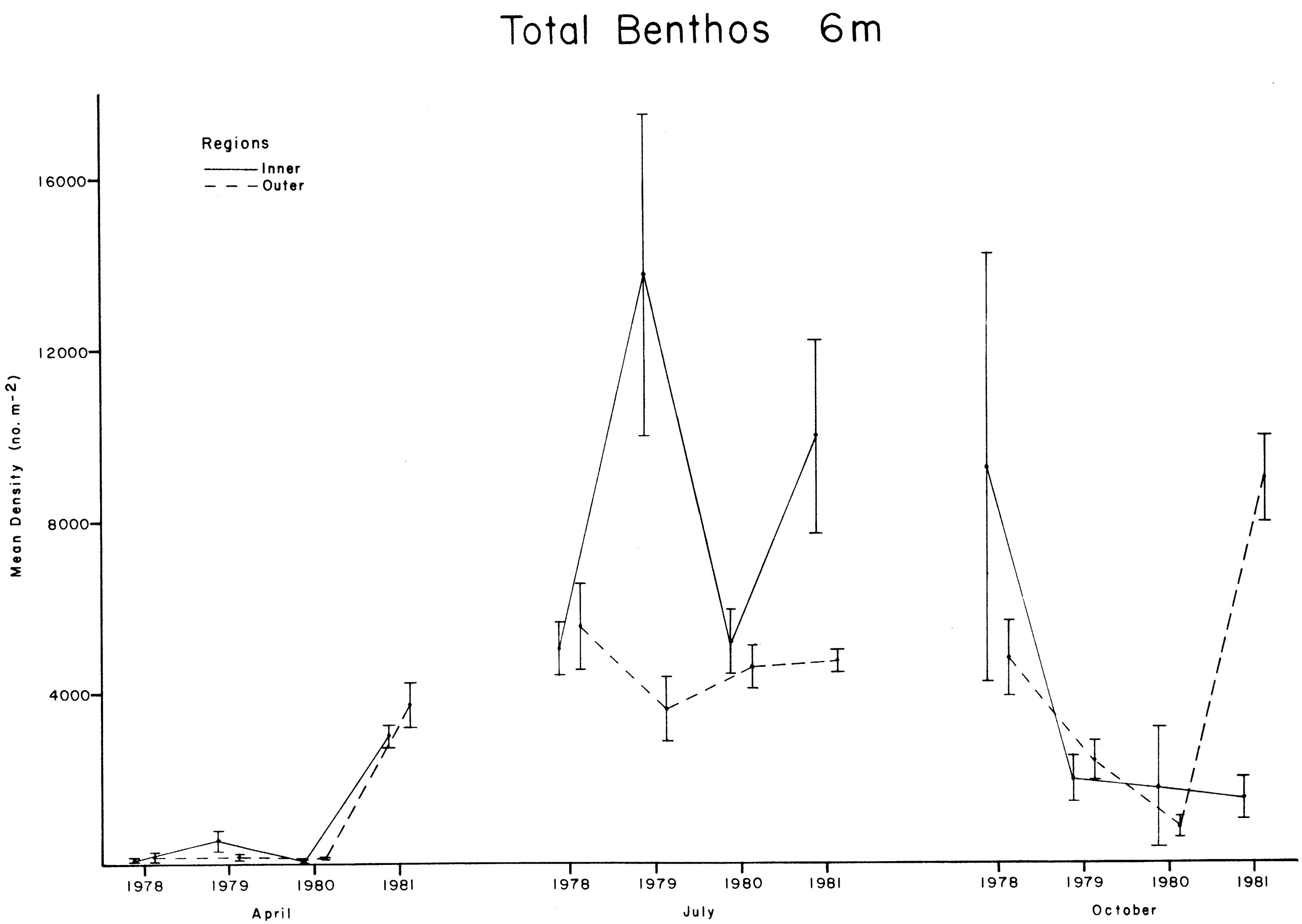

Fig. 31. Continued

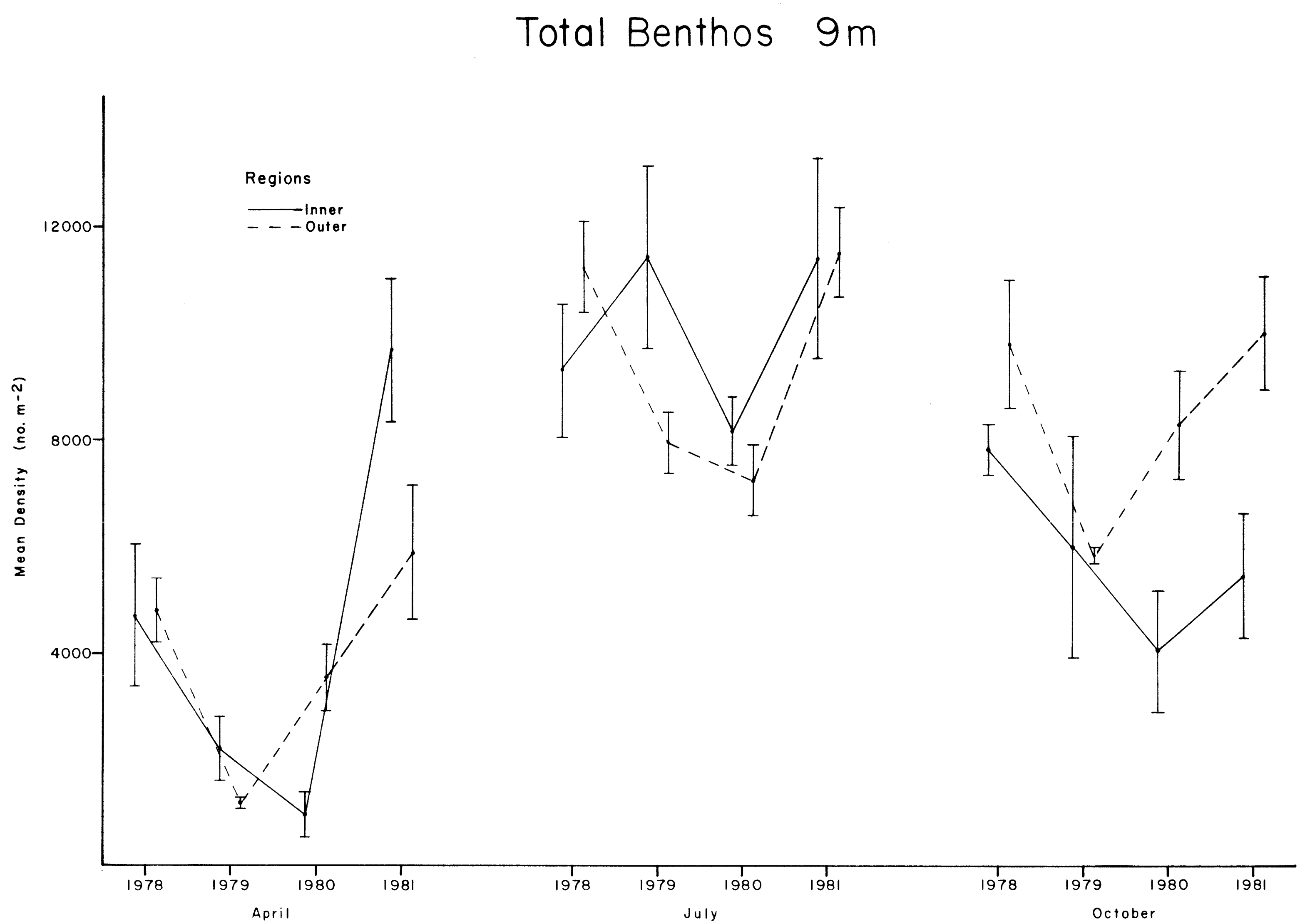

Fig. 31. Continued

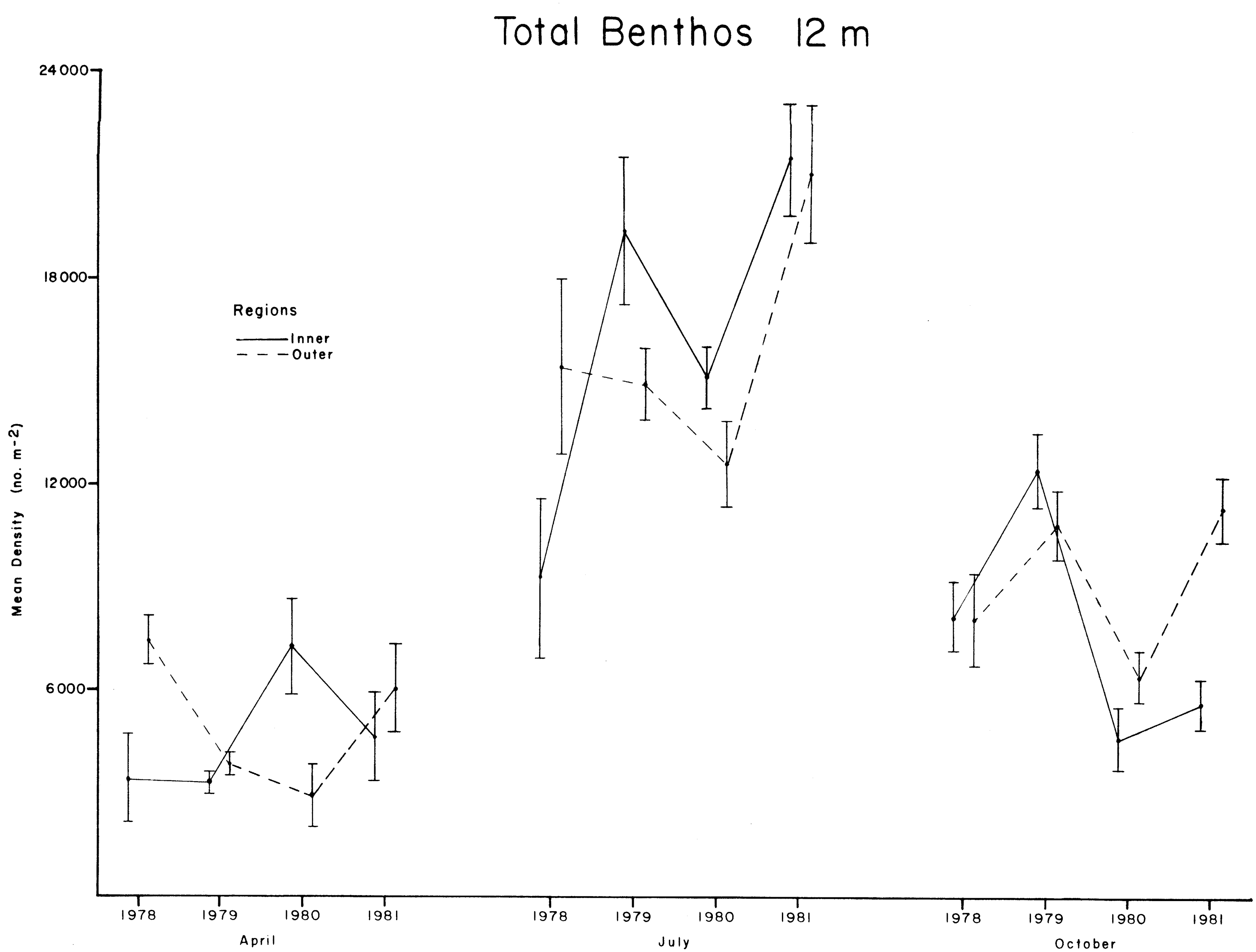

Fig. 31. Continued

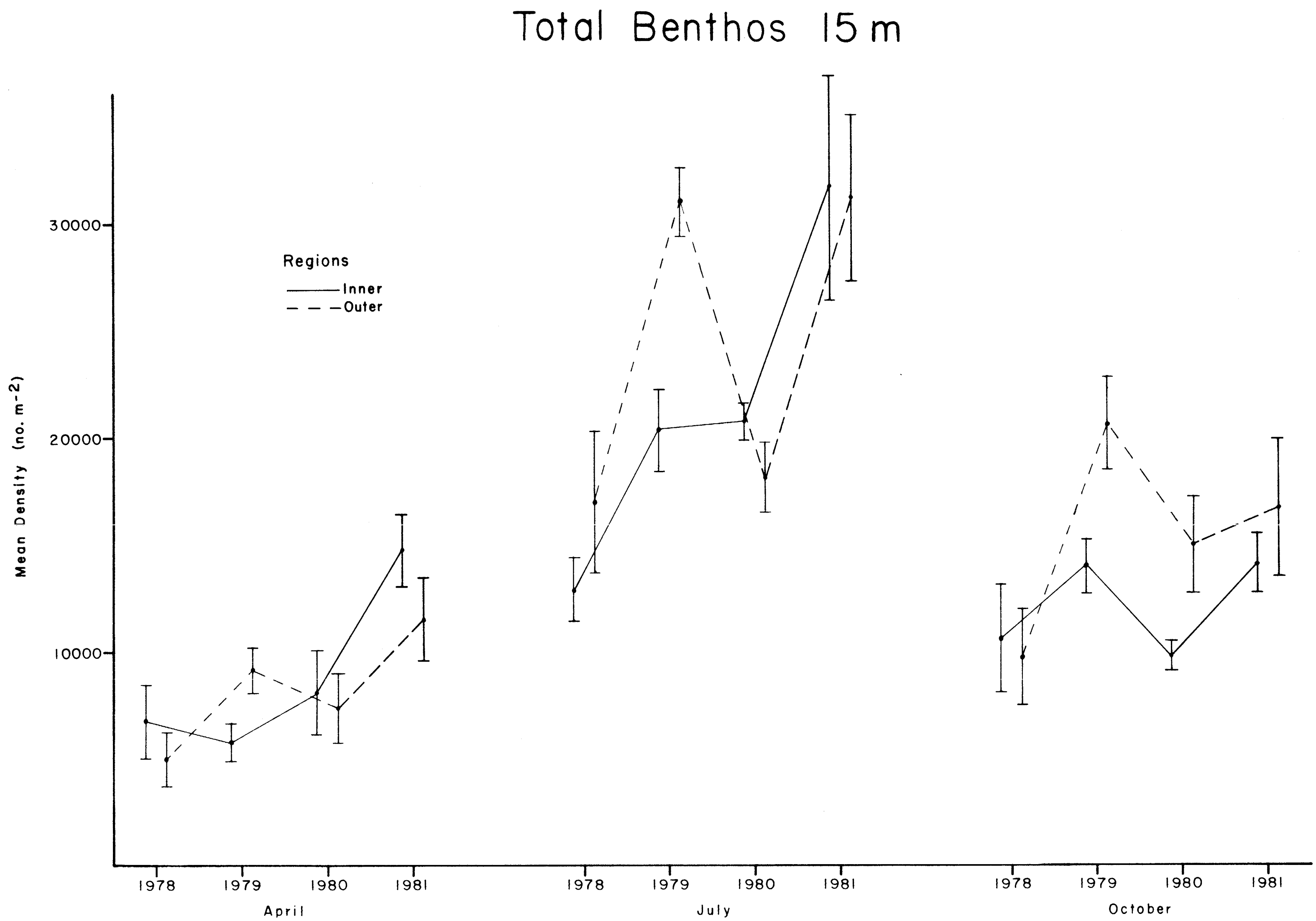

Fig. 31. Continued

Table 16. Analysis of variance results for total benthic densities [$\log_{10}(x+1)$] occurring at 3-15 m from 1978-1981 near the J.H. Campbell Plant, eastern Lake Michigan [NS = no significance ($p > 0.05$), * = $0.01 < p \leq 0.05$, ** = $0.001 < p \leq 0.01$, *** = $p \leq 0.001$].

Parameter	Sum of squares	Degrees of freedom	Mean square	F-ratio	Signif.
Region(R)	4.63	1	4.63	3.62	NS
Depth(D)	212.39	4	53.10	42.14	***
Month(M)	128.90	2	64.45	15.53	**
Year(Y)	17.30	3	5.77	41.21	***
RD	7.01	4	1.75	0.98	NS
RM	4.09	2	2.04	2.62	NS
DM	48.93	8	6.12	4.86	**
RY	3.83	3	1.28	9.14	***
DY	15.10	12	1.26	9.00	***
MY	24.88	6	4.15	29.64	***
RDM	3.16	8	0.39	0.48	NS
RDY	21.49	12	1.79	12.79	***
RMY	4.65	6	0.78	5.57	***
DMY	30.19	24	1.26	9.00	***
RDMY	19.48	24	0.81	5.79	***
Error	86.75	600	0.14		

Conclusions--

Based on the 4-yr design and R' and R values, we concluded that no measurable plant effect due to discharge of heated effluent into Lake Michigan was observed in benthic density fluctuations among nine taxa and total benthos occurring in the 3- to 15-m depth range during 1978-1981. As we have indicated, the nature of the test did not totally eliminate the possibility there may have been a plant effect below the limit of detection. However, density differences below the limit of detection were considered negligible, and given the variability in the system, would be very difficult to document without greatly increasing the sampling effort. Taking into account inherent variability and regional differences, density changes exceeding the limit of detection would have strongly indicated a plant effect, although not absolutely, as there may have been other unmeasured factors causing a difference.

Values of R' were generally quite low, ranging from 1.22 to 2.81. Low R' values indicated there was overall minimal density change among respective population densities, in spite of large, sporadic temporal density differences. While temporal density differences may be of importance for studies of life history, in an impact study, these differences are of interest, but by necessity, must be viewed on a long-term basis to assess their importance. For this reason, it is important to reiterate the high priority

to which impact studies must place on long-term data collection procedures employing extensive sampling effort in the context of a well-conceived statistical design. Unfortunately, in the present case, the vagaries of constructing and initiating operation of Unit 3 did not correspond as planned with the statistical design, resulting in an unbalanced design in need of alteration. Clearly, more than 1 operational yr would have been preferable. While we can only speculate on what effect additional operational years may have on our conclusions, we feel the alteration of the original design did not have a negative effect on results obtained or conclusions drawn. Based on our experience at the Cook Plant where results of both designs were compared (unpublished data, GLRD), conclusions were identical.

ARTIFICIAL SUBSTRATE STUDY ON THE INTAKE RIPRAP

Benthic macroinvertebrates collected from the five artificial substrate replicates were represented by 15 taxa (Table 17). Chironomids were most diverse being represented by seven taxa. Of the seven chironomid taxa, as well as with most remaining taxa collected from the artificial substrates, all except *Paratanytarsus* sp. and *Rheotanytarsus* sp. were collected by Ponar grabs from surrounding sandy substrates in the lake proper. As both *Paratanytarsus* sp. and *Rheotanytarsus* sp. form tubes adhering to firm substrates, e.g., rock and plant stems, their presence on

Table 17. Abundance of each taxon collected from artificial substrate samples (A-E), with corresponding mean density (no. m^{-2}), standard error, and percentage of total benthos. All animals were collected during 1981 from artificial substrates placed on the riprap surrounding the intake structure for Unit 3 at the J.H. Campbell Power Plant, eastern Lake Michigan (* = percentage of total Chironomidae or Naididae for species of each group, respectively).

Taxon	Sample A	Sample B	Sample C	Sample D	Sample E	Mean density	Standard error	% of total benthos
Gammarus spp.	85.7	285.6	28.6	114.2	180.9	139.0	44.1	8.2
Asellus sp.	228.5	361.8	76.2	637.8	257.0	312.3	93.3	18.5
Physella sp.	123.8	114.2	57.1	171.4	152.3	123.8	19.5	7.3
Hirudinea	9.5	9.5	9.5	0.0	0.0	5.7	2.3	0.3
Turbellaria	1056.7	180.9	209.4	485.4	285.6	443.6	162.3	26.2
Chironomidae	0.0	85.7	0.0	9.5	19.0	22.8	16.1	1.3
Endochironomus sp.	0.0	9.5	0.0	9.5	0.0	3.8	2.3	16.7*
Glyptotendipes (*P.*) sp.	0.0	9.5	0.0	0.0	0.0	1.9	1.9	8.3*
Nanocladius sp.	0.0	0.0	0.0	0.0	19.0	3.8	3.8	16.7*
Parachironomus sp.1	0.0	19.0	0.0	0.0	0.0	3.8	3.8	16.7*
Paratanytarsus sp.	0.0	9.5	0.0	0.0	0.0	1.9	1.9	8.3*
Rheotanytarsus sp.	0.0	9.5	0.0	0.0	0.0	1.9	1.9	8.3*
Saetheria cf. *tylus*	0.0	28.6	0.0	0.0	0.0	5.7	5.7	25.0*
Naididae	0.0	1256.6	9.5	1704.1	257.0	645.4	351.2	38.1
Chaetogaster diaphanus	0.0	1237.6	9.5	1704.1	257.0	641.6	349.5	99.4*
Nais variabilis	0.0	19.0	0.0	0.0	0.0	3.8	3.8	0.6*
Total benthos	1504.2	2294.3	390.3	3122.6	1151.9	1692.7	470.7	-

the riprap was not unexpected. In addition, the abundance of *Gammarus* spp. (*Gammarus fasciatus* and *G. pseudolimnaeus*) and *Asellus* sp. was considerably different than that encountered from surrounding sandy substrates. Whereas *Gammarus* spp. averaged 139 m^{-2} (8% of total benthic density) and *Asellus* sp. averaged 313 m^{-2} (19% of total benthic density) on the riprap, in sandy substrates neither animal was collected prior to 1981. During 1981, occurrence of both animals was restricted to the inner region [*Gammarus fasciatus* (2.7 m^{-2}), *Asellus* sp. (8.8 m^{-2})]. Considering the difference between sampling techniques, a fairly similar ratio of *Asellus*-to-*Gammarus* was observed (riprap substrate = 3.3, inner region sandy substrate = 2.2).

Hydra sp. had the highest density among macroinvertebrates occurring on the riprap. Colonies of *Hydra* sp. are suspected to occur over large areas of the riprap where water flow and food supply are sufficient. These animals occur in colonies of budding, but not separate individuals. When samples are processed for sorting purposes, there is no accurate way to determine the number of individuals present as the washing and handling process breaks juvenile individuals prematurely from the adult, making it virtually impossible to accurately discriminate free-living adult individuals from developing progeny.

Of enumerated taxa, the most abundant form was naidids (38% of the benthos) which was comprised almost entirely by

Chaetogaster diaphanus (99.4%). The only other naidid encountered was *Nais variabilis*.

The second-most abundant benthic invertebrate on the artificial substrates was the turbellarians (26% of benthos). Like their counterpart in the benthic lake survey, turbellarian densities were quite variable among replicates. Other taxa of importance, expressed as a percentage of total benthic density, were *Asellus* sp. (19%), *Gammarus* sp. (8%), and the snail, *Physella* sp. (7%). Chironomids contributed very little to total benthic abundance (1.3%). While it was surprising that the chironomids were not more numerous, low densities may have been a function of poor sieve retention of early instars characteristic of fall months, presence of large numbers of *Hydra* sp., physical location of substrates, and substrates themselves. Clearly, for chironomids and other taxa, densities would be better estimated by more frequent estimates equally dispersed throughout the year. At present, data for both density and diversity largely represent an autumn estimate.

The density of benthos on the riprap is important in connection with potentially entrainable invertebrates. The most likely macroinvertebrates to be entrained are those that exhibit pelagic, migratory behavior. Of taxa encountered on artificial substrates, amphipods, chironomids, and naidids demonstrate the highest degree of migratory activity (Marzolf 1965; Wells 1968; Wiley and

Mozley 1978). Consequently, these same animals would be expected to occur in the water column of Lake Michigan and subsequently in entrainment samples.

EFFECTS OF ENTRAINMENT ON MALACOSTRACAN POPULATION BIOLOGY AND LAKE ECOLOGY

Malacostracan Abundance in the Vertical Water Column of Lake Michigan

General Distribution--

The percent compositions of malacostracans collected in both net and sled tows from Lake Michigan were similar. In order of decreasing density, *Pontoporeia hoyi*, *Mysis relicta*, and *Gammarus* spp. (*G. fasciatus* and *G. pseudolimnaeus*) were the dominant taxa in samples collected by both methods, with the former comprising 93% of the malacostracans in net tows and 75% in sled tows. *M. relicta* and *Gammarus* spp. comprised a higher portion of total malacostracan density in sled tows (14% and 11%, respectively) than among net tows (5% and 2%, respectively). All remaining malacostracan species, *Hyalella azteca*, *Crangonyx pseudogracilis*, and *Asellus* sp., were observed in relative abundances of less than 1% in net and sled tows (Table 18). Of these rare malacostracans, *Asellus* sp. did not occur in net tows as it is not a pelagic form, but a cryptic omnivore foraging on food sources supplied by the riprap substrate.

Table 18. Average density (no. x 10^{-3} m^{-3}) for malacostracans collected in net tows, sled tows, and entrainment samples (Entr) during 1981 near the J.H. Campbell Plant, eastern Lake Michigan (n = number of samples).

Taxon	Net	Sled	Entr
Pontoporeia hoyi	965.1	245.0	1809.4
Gammarus spp.	19.6	36.2	272.6
Crangonyx pseudogracilis	1.3	0.3	215.2
Hyalella azteca	0.3	0.5	1.1
Mysis relicta	50.0	45.4	68.8
Asellus sp.	0.0	0.1	3.7
Total	1036.4	327.5	2370.8
n	476	140	542

Diel Distribution--

Comparison of diel malacostracan densities from net and sled tows confirmed the expected nocturnal nature of these malacostracans. Of the two methods, diel activity was most strongly expressed among net tows, with malacostracan night densities being two orders of magnitude greater than day densities (Table 19). Net tow diel density differences were greatest for *M. relicta* and *P. hoyi*, with night densities being 336 times and 141 times greater than day densities, respectively. As was expected, because sled tows sampled very close to the lake bottom in which many of the nocturnally active malacostracans take shelter during daylight hours, diel ratios were not as extreme as those observed in net tows, but nonetheless were indicative of diel activity, having an overall night-to-day ratio of 5.2.

Depth Distribution--

Very low malacostracan abundances were observed in the 1- to 6-m depth range when compared with the 9- to 15-m depth range sampled by both net and sled tows (Table 20). This trend was particularly evident for *P. hoyi* and *M. relicta*. *P. hoyi* density averaged 17 x 10^{-3} m^{-3} (sled) and 11 x 10^{-3} m^{-3} (net) at depths less than 6 m, but 549 x 10^{-3} m^{-3} (sled) and 153 x 10^{-3} m^{-3} (net) at depths greater than 6 m. Similarly, *M. relicta* densities averaged 4.7 x 10^{-3} m^{-3} (sled) and 3.6 x 10^{-3} m^{-3} (net) at depths less than 6 m, but 100 x 10^{-3} m^{-3} (sled) and 78 x 10^{-3} m^{-3} (net) at

Table 19. Diel malacostracan abundance (no. x 10^{-3} m^{-3}) in net and sled tow samples (April-September 1981) and entrainment samples (January-December 1981) collected near the J.H. Campbell Plant, eastern Lake Michigan (n = number of samples).

Taxon	Net		Sled		Entrainment			
	Day	Night	Day	Night	Dawn	Day	Dusk	Night
Pontoporeia hoyi	13.7	1932.5	59.5	430.5	719.0	109.7	697.9	5763.6
Gammarus spp.	4.3	35.3	23.3	49.1	259.4	188.9	293.0	353.2
Crangonyx pseudogracilis	0.9	1.8	0.0	0.7	179.5	123.3	245.6	315.6
Hyalella azteca	0.1	0.4	0.0	1.0	2.4	0.6	0.4	1.1
Mysis relicta	0.3	100.7	21.9	68.8	85.2	2.0	19.6	173.6
Asellus sp.	0.0	0.0	0.0	0.3	0.5	2.3	2.6	9.2
Total	19.3	2077.5	104.7	550.4	1246.1	426.9	1259.1	6616.3
n	240	236	70	70	128	143	136	135

Table 20. Average malacostracan abundance (no. x 10^{-3} m^{-3}) at each depth sampled from April through September near the J.H. Campbell Plant, eastern Lake Michigan. Net tow samples were averaged over all horizontal depths sampled at each station (from 0.5 m below surface to 0.5-1.0 m above bottom). Sled tow samples estimated densities occurring very near bottom (n= number of samples).

Taxon	Net 1.0 m	1.5 m	3.0 m	6.0 m	9.0 m	12.0 m	15.0 m
Pontoporeia hoyi	13.2	1.0	2.7	17.2	223.4	1203.3	3159.0
Gammarus spp.	47.3	8.5	20.0	15.1	24.0	25.9	4.2
Crangonyx pseudogracilis	5.2	0.0	0.6	1.0	0.2	0.6	2.5
Hyalella azteca	0.0	2.2	0.0	0.0	0.6	0.0	0.3
Mysis relicta	0.0	2.6	4.4	5.1	34.1	81.1	117.7
Asellus sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	65.7	14.3	27.7	38.5	282.3	1310.9	3283.7
n	38	29	49	79	199	99	199

Taxon	Sled 1.0 m	1.5 m	3.0 m	6.0 m	9.0 m	12.0 m	15.0 m
Pontoporeia hoyi	7.6	21.4	9.0	29.5	452.5	600.8	594.2
Gammarus spp.	41.1	36.1	53.9	23.9	83.8	5.7	8.9
Crangonyx pseudogracilis	2.3	0.0	0.0	0.0	0.0	0.0	0.0
Hyalella azteca	0.0	0.0	0.0	0.0	0.0	2.0	1.6
Mysis relicta	4.6	0.0	5.3	8.9	54.8	109.7	134.2
Asellus sp.	0.0	0.0	0.0	0.0	0.9	0.0	0.0
Total	55.5	57.5	68.3	62.2	592.1	718.2	738.9
n	29	29	29	29	29	29	29

depths greater than 6 m. However, _Gammarus_ spp. and _C. pseudogracilis_ densities did not increase with depth, but rather were generally similar at depths less than 15 m. In addition, once in the water column _Gammarus_ spp., _C. pseudogracilis_, and _H. azteca_ occurred in greatest densities near the surface as opposed to mid- and near bottom depths in the water column. _P. hoyi_ and _M. relicta_ were strongly depth-dependent in the water column, occurring most abundantly in the deeper half of the water column. This difference may reflect the relative swimming abilities of the two groups. _P. hoyi_ and _M. relicta_ are strong swimmers capable of a great degree of vertical mobility. Remaining taxa are comparatively weaker swimmers and, while capable of entering the water column, they may not be strong enough swimmers to effectively control their vertical position, with subsequent concentration near the surface.

Seasonal Development and Distribution--

The seasonal development of _P. hoyi_ based on both net and sled tows followed that expected from benthic samples collected during April, July, and October, but additionally conformed well with the more extensive sampling effort conducted near the Cook Plant (unpublished data, GLRD). The basic April through September development pattern was as follows: primarily spent and gravid females and young-of-the-year individuals in April, primarily recently released juvenile individuals in May and June (<3 mm), and developing

juveniles in July, August, and September (3 to 5 mm) (Table 21). These data indicated not only the seasonal changes in size of *P. hoyi* individuals, but that net tows, sled tows (Table 21), and Ponar grab sampling (Appendix 1) methods provided fairly similar estimates of the developmental pattern of the population during this time period.

Seasonally, greatest densities of *P. hoyi* were found during summer months in both net and sled tows (Table 22). Peak abundances of *P. hoyi* occurred during July (3,752 x 10^{-3} m^{-3}) in net tows and during August (625 x 10^{-3} m^{-3}) in sled tows.

Seasonal distribution of mysids based on net tows indicated similar densities occurred April through June (approximately 20 to 30 x 10^{-3} m^{-3}), peak abundance in July (171 x 10^{-3} m^{-3}), and decreasing density to very low levels by September (1 x 10^{-3} m^{-3}). In contrast, among sled tows lowest mysid abundance was observed in July (4 x 10^{-3} m^{-3}), with August (122 x 10^{-3} m^{-3}) and September (58 x 10^{-3} m^{-3}) densities being highest among the monthly estimates (Table 22). Whereas the monthly density trends for *P. hoyi* and *Gammarus* spp. occurring in net and sled tows were similar, the lack of monthly comparability for *M. relicta* is suspected to be directly related to the migratory nature of mysids in relation to weather, upwelling, and coincidental sampling with these events, as well as any non-synchrony of sampling effort between sled and net tows.

Table 21. Seasonal distribution and development of *Pontoporeia hoyi* based on 1-mm size classes and the reproductive status of individuals (as a percentage of total *P. hoyi* density) collected in net and sled tows, respectively, averaged over all depths sampled during 1981 near the J.H. Campbell Plant, eastern Lake Michigan. Mean density expressed as no. m^{-2} (n = number of samples).

	April		May		June		July		August		September	
Size class	Net	Sled	Net	Sled	Net	Sled	Net	Sled	Net	Sled	Net	Sled
1.0-1.9 mm	0.0	0.0	57.2	77.0	2.2	2.2	0.0	0.0	<0.1	2.2	1.5	0.0
2.0-2.9 mm	0.0	0.0	1.7	10.1	83.1	71.2	32.6	31.2	12.3	2.9	11.3	7.7
3.0-3.9 mm	0.0	0.0	0.0	0.0	13.7	24.4	65.7	59.8	70.8	72.1	65.2	33.6
4.0-4.9 mm	8.3	0.0	0.0	0.8	0.0	0.6	1.2	8.3	15.8	21.1	20.6	42.7
5.0-5.9 mm	21.4	10.0	6.5	0.0	0.2	0.1	<0.1	0.3	0.8	0.3	1.5	13.5
6.0-6.9 mm	49.8	18.6	21.9	0.0	0.7	0.6	<0.1	2.9	0.2	0.7	0.0	2.4
7.0-7.9 mm	21.0	62.9	10.3	11.3	0.2	0.0	0.4	0.0	0.0	0.7	0.0	0.0
8.0-8.9 mm	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Juvenile	43.2	8.6	88.7	87.8	100.0	100.0	>99.9	100.0	100.0	99.5	100.0	100.0
Gravid	4.8	7.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spent	52.0	83.6	11.6	11.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Males	0.0	0.0	0.0	0.8	0.0	0.0	<0.1	0.0	0.0	0.0	0.0	0.0
Mean density	22.9	14.0	29.2	83.8	240.9	161.0	3751.5	290.7	749.6	624.9	20.4	115.3
n	48	14	95	28	93	28	96	28	96	28	48	14

Table 22. Summary of average monthly densities (no. x 10^{-3} m^{-3}) for all malacostracans collected in net and sled tows averaged over all depths during 1981 near the J.H. Campbell Plant, eastern Lake Michigan (n = number of samples).

Taxon	April		May		June		July		August		September	
	Net	Sled	Net	Sled	Net	Sled	Net	Sled	Net	Sled	Net	Sled
Pontoporeia hoyi	22.9	14.0	29.2	83.8	240.9	161.0	3751.5	290.7	749.6	624.9	20.4	115.3
Gammarus spp.	2.0	0.0	1.3	2.6	9.7	1.8	9.9	11.9	48.4	62.8	55.0	204.0
Crangonyx pseudogracilis	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	1.8	1.6	7.8	0.0
Hyalella azteca	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	5.2
Mysis relicta	19.0	6.3	27.2	48.5	26.0	20.8	170.5	3.7	15.6	121.6	1.2	58.1
Asellus sp.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0
Total	45.3	29.3	57.7	134.9	277.5	183.6	3931.8	396.2	815.4	811.6	119.3	382.6
n	48	14	95	28	93	28	96	28	96	28	48	14

A significant difference between mysids and all remaining malacostracans observed in the survey area was that the bulk of the mysid population occurred in the profundal water of Lake Michigan (>70 m), thereby necessitating migration over a considerable distance in order to occur in samples at depths less than 15 m. In addition, because mysids are very adept swimmers with very good visual perception of light, their ability to avoid mid-water sampling devices as well as benthic sampling devices is adequate enough to not regard observed densities with the same degree of reliability as one would with other benthic macroinvertebrates. Finally, due to the migratory nature of mysids, monitoring of seasonal development of mysids caught at depths less than 15 m may not be representative of the total population. Consequently, little can be stated regarding seasonal development of the mysid population.

Gammarus spp. exhibited greatest reproductive activity during late summer. With occurrence of maximum reproductive activity and newly recruited individuals, greatest monthly gammarid abundances were observed during August and September in net and sled tows (Table 22).

Entrainment of Malacostracans by Pumping Operations at Unit 3

General Distribution--

As was the case in net and sled tows, malacostracan entrainment density estimates were dominated by *P. hoyi*, which comprised 76% (1,809 x 10^{-3} m^{-3}) of all entrained

malacostracans (Table 18). Gammarids were the second- and third-most numerously entrained taxa, with *Gammarus* spp. (*Gammarus fasciatus* and *Gammarus pseudolimnaeus*) averaging 273 x 10^{-3} m^{-3} and *C. pseudogracilis* 215 x 10^{-3} m^{-3}. However, the second-most abundantly occurring malacostracan in net and sled tows, *M. relicta*, was only the fourth-most abundantly entrained malacostracan (69 x 10^{-3} m^{-3}).

As entrained malacostracans originated from Lake Michigan, directly comparing entrainment samples (collected from January through December) with net tows (collected from April through September), to determine how representative the former is of the latter, requires examining both sampling methods on an April to September basis. In addition, it is necessary to restrict net tows to the lower half of the water column at a depth of 9 to 15 m as the intake structure entrained water from a lake depth of 11 m at a vertical height above bottom of 1 to 3 m. When these restrictions were placed upon the comparisons, extremely similar results were obtained. Entrainment of *P. hoyi* and *M. relicta* averaged 2,347 x 10^{-3} m^{-3} and 101 x 10^{-3} m^{-3}, respectively, from April through September. Average net tow density of these species was 2,407 x 10^{-3} m^{-3} and 127 x 10^{-3} m^{-3}, respectively. From these comparisons, it was evident that entrainment samples were very representative of densities in the water column of Lake Michigan in the inner

region. However, dissimilar densities were noted among gammarids collected by the same two methods.

A very significant difference between entrainment sample and net tow gammarid densities was observed. High numbers of _Gammarus_ spp. ($387 \times 10^{-3}\ m^{-3}$) and _C. pseudogracilis_ ($308 \times 10^{-3}\ m^{-3}$) were entrained when compared with quite sparse numbers in net tows ($12 \times 10^{-3}\ m^{-3}$ and $0.7 \times 10^{-3}\ m^{-3}$, respectively). With respect to densities of entrained gammarids, the protective riprap covering the bottom area near the intake structures provided an ideal environment for establishment of _Gammarus_ spp. and _C. pseudogracilis_ populations. These species occur on rock surfaces in several locations throughout the Canadian shoreline of the Great Lakes (Barton and Hynes 1976). In addition, _Gammarus_ spp. occur on the riprap at the Cook Plant, although _Crangonyx_ has not been observed. Artificial substrates placed in the riprap at Campbell were colonized by _Gammarus_ spp., but not by _Crangonyx_. While _Crangonyx_ was not observed on the artificial substrates, its frequent occurrence and abundance in entrainment samples strongly suggest it has established a large population on the riprap.

With respect to net tow gammarid densities, the net tow sample site was located slightly north of the riprap area above sandy substrates. Due to the distance from the riprap which supported a large gammarid population, net tows collected few gammarids. As the gammarids encountered in the study area are best adapted for movement among algae and

periphyton growing on rocky substrates, few would be expected to occur in an area dominated by shifting sands, where movement would be largely limited to burrowing or pelagic adaptations common to *P. hoyi* and *M. relicta*. Once in the water column, both *P. hoyi* and *M. relicta*, being strong swimmers, burrowers, and migrators, were distributed in similar mean abundance over a wide area, irrespective of benthic substrate. Subsequently, occurrence of few gammarids in net tows, but many in entrainment samples, was directly related to behavioral adaptions of the gammarids. This suggests that the location of net tows greatly affected observed gammarid density, but had no effect on the density of either *P. hoyi* or *M. relicta*. We conclude that the lack of comparability between gammarid densities in entrainment samples and net tows was directly attributable to the location of net tow sampling in relation to the riprap surrounding the intake structures.

Diel Distribution--

Entrainment of malacostracans peaked at night and was lowest during daylight (Table 19). Dawn and dusk periods had similar densities which were intermediate to those of the night and day periods. Generally, malacostracan entrainment was 16 times greater at night than during the day, but ranged from as high as 87 times greater for *M. relicta* and 53 times greater for *P. hoyi* to as low as two times greater for *H. azteca*. Excepting the former two

species, the night-to-day ratio was less than five for all remaining taxa. While the absolute ratios differed among net tows, sled tows, and entrainment samples, the general diel trend was the same.

Seasonal Distribution and Development--

Considerable numbers of *P. hoyi* were entrained during June (2,293 x 10^{-3} m^{-3}), July (8,893 x 10^{-3} m^{-3}), and December (5,154 x 10^{-3} m^{-3}) (Table 23). Maximum peak entrainment densities corresponded well with times when one might expect greater numbers of *P. hoyi* to be entrained due to recruitment from winter reproductive activity. *P. hoyi* entrained in June and July were the present year class of <5-mm individuals recruited into the population during May. Those entrained during December were primarily the highly mobile, pelagic males present only during winter months, the time of maximum reproductive activity (Table 24). Large numbers of males were also observed at the Cook Plant in December and January (unpublished data, GLRD). Males continued to be the dominate reproductive form in entrainment samples from December through March at the Campbell Plant. Gravid females, which were most evident during February, had released their young by April because spent females dominated during April. Newly released young were first evident in entrainment samples during May. This seasonal development cycle closely followed that observed among entrainment samples collected at the Cook Plant

Table 23. Summary of average monthly densities (no. x 10^{-3} m^{-3}) for all malacostracans collected in entrainment samples during 1981 at the J.H. Campbell Plant, eastern Lake Michigan (n = number of samples).

Taxon	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pontoporeia hoyi	590.5	121.9	7.7	7.1	68.4	2292.6	8892.6	682.7	682.7	296.0	62.5	5153.7
Gammarus spp.	3.9	5.7	5.7	42.1	44.9	237.5	377.5	1120.4	518.3	200.5	243.2	8.1
Crangonyx pseudogracilis	24.7	21.4	45.6	135.1	109.9	121.2	207.2	1071.7	302.6	130.6	139.9	6.0
Hyalella azteca	0.0	0.0	0.0	0.8	0.9	2.2	0.0	0.0	0.7	6.0	0.0	0.6
Mysis relicta	23.9	24.8	10.1	4.0	106.4	86.0	227.8	36.1	92.2	17.2	15.3	17.2
Asellus sp.	0.0	1.2	0.0	0.6	3.6	7.2	17.2	0.0	0.3	0.3	0.6	4.3
Total	643.9	175.9	69.1	189.7	334.1	2746.6	9722.4	2919.9	1596.7	650.1	461.5	5189.9
n	28	32	32	36	69	64	62	48	61	55	32	32

Table 24. Seasonal distribution and development of *Pontoporeia hoyi* based on 1-mm size classes and the reproductive status of individuals (as a percentage of total *P. hoyi* density) collected in entrainment samples during 1981 at the J.H. Campbell Plant, eastern Lake Michigan. Mean density expressed as no. m^{-2} (n = number of samples).

Size class	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.0-1.9 mm	0.0	0.0	0.0	0.0	43.4	0.4	0.0	0.0	1.3	0.0	3.5	0.0
2.0-2.9 mm	0.0	0.0	0.0	0.0	55.4	42.2	9.2	13.1	22.6	0.5	5.9	0.1
3.0-3.9 mm	0.0	0.0	0.0	0.0	0.6	55.1	82.0	53.3	66.9	33.6	9.1	0.1
4.0-4.9 mm	2.3	2.8	24.7	0.0	0.0	1.1	8.6	32.0	8.1	58.0	39.7	0.5
5.0-5.9 mm	31.4	31.6	39.0	45.8	0.0	0.3	0.1	1.2	0.8	7.5	37.1	4.1
6.0-6.9 mm	55.0	41.3	23.4	41.7	0.0	0.1	0.1	0.4	0.2	0.3	4.6	22.5
7.0-7.9 mm	9.2	23.5	13.0	12.5	0.6	0.9	0.0	0.0	<0.1	0.0	0.0	53.7
8.0-8.9 mm	2.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.7
9.0-9.9 mm	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Juvenile	15.8	24.4	45.5	70.4	99.4	100.0	100.0	100.0	>99.9	100.0	100.0	1.5
Gravid	2.4	23.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Spent	0.0	2.6	0.0	21.1	0.6	0.0	0.0	0.0	<0.1	0.0	0.0	0.3
Male	81.8	49.6	53.3	8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	98.1
Mean density	590.5	121.9	7.7	7.1	68.4	2292.6	8892.6	682.7	682.7	296.0	62.5	5153.7
n	28	32	32	36	69	64	62	48	61	55	32	32

(unpublished data, GLRD) and that observed in net and sled tows at the Campbell Plant.

Mysids were entrained in greatest numbers from May through September; density peaked during July (228×10^{-3} m^{-3}) (Table 23). The majority of entrained mysids were less than 6 mm in length, evidently individuals of the current year class. Although juvenile mysids were dominant during most months, males and females were dominant forms in January and February, suggesting maximum reproductive activity occurred during winter.

While the seasonal development of mysids, based on individuals collected in entrainment samples at the Campbell Plant, was similar to that observed in entrainment samples at the Cook Plant (unpublished data, GLRD), seasonal distribution of mysids was markedly different. Greatest average mysid density at the Cook Plant (1975 to 1978) occurred in January during suspected maximum onshore reproductive activity, with the majority entrained being males. However, mysid entrainment densities were low during summer. This general entrainment pattern at the Cook Plant was reversed from that at the Campbell Plant. The most likely explanation of this difference is that sampling effort (during January in particular) at the Campbell Plant did not coincide with onshore migration of the mysid population to the extent that this event was noted in Cook entrainment samples. Entrainment sampling during 1981 at the Campbell Plant occurred on 15 and 29 January and on 21

to 24 December. Quite coincidentally, Cook Plant entrainment samples during January 1981 were collected on the 12th and 27th. Comparison of the Cook Plant average mysid entrainment density estimated from nearly the same days with the Campbell Plant average mysid entrainment density indicated mysids were entrained in similar densities at each plant during January (27×10^{-3} m^{-3} and 24×10^{-3} m^{-3}, respectively) and that onshore-migrating mysids were not heavily entrained by either plant during January 1981.

It is apparent that onshore migration of mature mysids occurs from mid-December through January or February. Observing an order of magnitude decline in mysid density from October to December at >30-m stations in Lake Michigan, Grossnickle and Morgan (1979) speculated that the decline may be due to onshore or offshore migration. Onshore mysid migration was supported by Cook Plant entrainment data which showed that the moderate increase in mysid density in December was followed by a large increase in average mysid density in January. During February, mysid abundance returned to normal levels at the >30-m stations (Grossnickle and Morgan 1979). Similarly, entrainment of mysids decreased during the February and March time period at the Cook Plant to moderate densities which were followed by low abundances from April through August. While the correlation is in need of more rigorous documentation, there exists the potential for demonstrating an early to mid-winter, onshore migration and a late winter, offshore migration.

Gammarus spp. were highly abundant during summer and fall months (Table 23). Based on presence of males and reproductive females, reproduction occurred throughout the summer months, with peak recruitment of young during late summer. Following the fall months, abundance of *Gammarus* spp. decreased notably from approximately 200 x 10^{-3} m^{-3} to less than 10 x 10^{-3} m^{-3} from December through March. With the continual decrease of water temperature and day length during fall months, food may be sufficiently depleted to induce starvation which, along with predation, may reduce the overwintering population to the low levels observed.

Impact of Entrainment on Malacostracans

Pontoporeia hoyi--

Based on the maximum pumping rate at Unit 3 and an average *P. hoyi* density in entrainment samples of 1.809 m^{-3}, maximum annual entrainment of *P. hoyi* was 1.17 x 10^9 yr^{-1}. However, as Unit 3 did not pump at maximum capacity at all times during the year, actual entrained *P. hoyi* on an annual basis using the average measured pumping rate (1.115 x 10^6 m^3 day^{-1}) was 7.36 x 10^8 yr^{-1}. Assuming a 2-km^2 area in the immediate vicinity of the intake structures of Unit 3 as the area in Lake Michigan most likely to be impacted by plant operations, the total number of *P. hoyi* available to entrainment processes was 1.54 x 10^{10}, based on the inner region benthic density at 3 to 15 m during 1981 (3,849 m^{-2}). Using these density estimates to approximate the potential

impact of entrainment, approximately 4.9% of _P. hoyi_ occurring in a 2-km^2 area was entrained during 1981. The proportion of annually entrained _P. hoyi_ could be as high as 7.6% were maximal pumping assumed throughout the year.

Similar calculations utilizing _P. hoyi_ ash-free dry weight biomass estimates indicated 518 to 820 kg yr^{-1} were entrained during 1981 at the Campbell Plant. When compared with the total benthic biomass available in the 2-km^2 area, annually entrained biomass accounted for 8.4 to 13.3% of benthic _P. hoyi_ biomass depending upon the pumping rate assumed.

When compared with similar maximal pumping rates estimated at the Cook Plant [1.46×10^8 yr^{-1} and 297 kg yr^{-1} (ash-free dry weight); unpublished data, GLRD], the Campbell Plant entrained 8.0 times as many _P. hoyi_ as did the Cook Plant and 2.8 times the biomass entrained at Cook. The low Campbell-to-Cook entrained biomass ratio was at least partially due to the method of calculating biomass (Campbell calculations used 0.5-mm size classes; whereas, at Cook much broader size classes were utilized: <3 mm, 3-5 mm, 5-7 mm, and ≥7 mm.

Possibly the inter-plant comparison that best accounts for annual pumping rates, entrainment rates, and benthic densities of _P. hoyi_, is the ratio of the benthic area required annually to supply the number of _P. hoyi_ annually entrained. At the Campbell Plant this area is maximally equivalent to 3.04×10^5 m^2 yr^{-1} (= 1.17×10^9 _P. hoyi_

yr^{-1}/3,849 *P. hoyi* m^{-2}). At the Cook Plant the similar area is maximally equivalent to 1.93×10^5 m^2 yr^{-1} (= 1.46×10^8 *P. hoyi* yr^{-1}/757 *P. hoyi* m^{-2}). As the ratio of these two numbers compares equally the relative impact of annual entrainment on the average benthic density of *P. hoyi*, regardless of entrainment rate, pumping rate, and benthic density differences between plants, the relative effect of entrainment of *P. hoyi* was 1.58 times greater at the Campbell Plant when compared with the Cook Plant. As previously noted, this corresponds maximally to 7.6% of the average available *P. hoyi* population in a 2-km^2 area near the Campbell Plant. The equivalent estimate at the Cook Plant was 4.8%.

Given that the effect of entrainment of *P. hoyi* was approximately 50 to 60% greater at the Campbell Plant than at the Cook Plant, does this constitute a significant difference among relative plant impacts by upsetting either the population biology of *P. hoyi* or the general ecology in the 2-km^2 area maximally impacted in Lake Michigan by entrainment activities? Neither at the Campbell Plant nor at the Cook Plant (unpublished data, GLRD) were any changes observed that would indicate an alteration of the population had occurred due to entrainment. If it is assumed that all individuals passing through the plant were eliminated from the population, lake densities were altered. However, as benthic abundance of *P. hoyi* was so high in the area considered, we concluded that the loss to the population was

negligible. This is especially true if the nearshore population is viewed not as a static 2-km^2 area, but rather as a churning, swirling, constantly changing dynamism of benthic and pelagic environments experiencing both immigration and emigration of individuals. During tranquil periods the portion of the population near the intake structures may experience increased entrainment. Conversely, during turbulent periods the effect on any given portion of the population may be non-existent due to massive movements of the population. On an average day during the April to September time period, we calculated there were 4.61×10^7 _P. hoyi_ in the volume of water overlying the 2-km^2 area of concern. The number in the water column corresponded to 0.3% of the total available in the water mass overlying the 2-km^2 area. Marzolf (1965) estimated the percent of the _P. hoyi_ population occurring in the water column on 30 different dates in Grand Traverse Bay, Lake Michigan at 42 m. While estimates ranged from 0 to 7.4%, the average percentage of _P. hoyi_ occurring in the water column was 0.96%, suggesting that our estimate was not unreasonable.

As the maximal entrainment rate during this time period was 4.15×10^6 _P. hoyi_ on an average day, we determined 9.0% (maximal) or 6.0% (actual) of the pelagic population was entrained. Overall, we concluded from the 1981 density estimates that entrainment maximally affected about 7.6% of the benthic population or 9.0% of the pelagic population,

but given the ecological dynamics of *P. hoyi* and the physical dynamics of the lake, this effect is diffused over a broad spectrum of the population, not continually concentrated on a single sub-unit. This perspective, then, affects our interpretation of removal of *P. hoyi* on the general ecology in the area. We have assumed the effect of entrainment was on a dynamically changing *P. hoyi* population which dominated the benthic habitat at 9 to 15 m near the Campbell Plant. Under the assumption of a dynamically changing population model whereby lake-wide processes unite many sub-units of the population along the shoreline of eastern Lake Michigan, it is likely that the population is continually re-established at rates affected by weather, temperature, light, currents, and seasons. Overall, we have not observed among these data any trends that would lead us to suspect entrainment of *P. hoyi* has altered the general benthic ecology near the plant or the population biology of *P. hoyi*. A possible exception may be the effect entrainment exerts on reproductive success during winter months.

Quite possibly, the time when one might seriously consider the effect of entrainment on the population biology of *P. hoyi* is when massive numbers of pelagic males occur during peak nearshore reproductive activity in December and January. Based on annual entrainment estimates at Campbell and Cook, December and January samples were dominated by over 90% males. Males entrained during these 2 mo comprised 17% and 35%, respectively, of the total annually entrained

P. hoyi at each plant. If the average number of females fertilized by a single male and the average number of eggs fertilized by a single encounter were known, the maximum loss to the population by entraining a given number of males could be calculated, assuming entrained males had not fertilized any females and 100% survival of gravid females and brooding young until release from the marsupium as juveniles. However, without this information, no estimate can be generated and the significance of the loss of males during the peak reproductive period remains unknown.

Mysis relicta--

Maximum annual density of entrained *M. relicta* at the Campbell Plant was equivalent to 4.44×10^7 yr^{-1} or 19.1 kg yr^{-1} (dry weight). Using actual average daily pumping rates at Unit 3 from January through December, actual annual density of entrained mysids during 1981 was 2.80×10^7 yr^{-1} or 12.0 kg yr^{-1}. During the April through September time period, we calculated there were 2.39×10^6 mysids in the volume of water above the 2-km^2 area during any average day. As 1.79×10^5 mysids were maximally entrained daily during the same time period, we determined that 7.5% (maximal) or 5.0% (actual) of the mysids in the water column were entrained during the average day.

Although no benthic density estimates for *M. relicta* were available near the Campbell Plant, Morgan and Beeton (1978) estimated an average density of 188 m^{-2} from their

study site in the profundal zone of Lake Michigan near Milwaukee, Wisconsin. If this mysid benthic density was used to calculate the approximate number of mysids available for entrainment at any average time, assuming all were to migrate and were entrainable, then in a theoretical 2-km^2 area 7.52×10^8 mysids are available. Of this number an average 5.9% would be entrained at the Campbell Plant. Nearly twice as many mysids were entrained at the Cook Plant (8.05×10^7 yr^{-1}) than at the Campbell Plant. The mysids entrained at the Cook Plant comprised 10.7% of the theoretical 2-km^2 area density at that plant. The greater entrainment rate at the Cook Plant was due to the effect of December and January sampling which was more strongly affected by the mysid density than was the estimate from the Campbell Plant.

The validity of using a 2-km^2 area as a measure of entrainable _M. relicta_, given the migration distances and dynamics of the lake, is certainly questionable. Use of the theoretical area could just as easily be increased or decreased, with subsequent effects on percentages entrained, not just for mysids, but for amphipods as well. Its use serves only one purpose: to add perspective to the magnitude of the numbers or organisms entrained and those potentially entrainable. No absolute is implied by the percentages generated. However, it is interesting to note the extremely large numbers of mysids that are available for entrainment assuming 100% onshore migration. Without knowledge of

approximate benthic mysid densities at a site, the relative effect of entrainment at sites can not be fully evaluated. Current benthic density estimates for the mysid population are poorly known. In addition, very little is known about the degree of onshore migration by the mysid population. Consequently, the effect of entrainment on the population of *M. relicta* is even more poorly understood.

Gammarus spp. and *Crangonyx pseudogracilis*--

While annual entrainment could be determined, estimating the effect of entrainment on the populations of *G. fasciatus*, *G. pseudolimnaeus*, and *C. pseudogracilis* was specific to the month of October as the only estimate of benthic density was from artificial substrates retrieved during October. Annual entrainment of *Gammarus* spp. was estimated to have a maximum of 1.76×10^8 yr^{-1}, while that of *C. pseudogracilis* was 1.39×10^8 yr^{-1}. However, based on the actual average daily pumping rate at Unit 3, actual annual entrainment was 1.11×10^8 yr^{-1} for *Gammarus* spp. and 8.76×10^7 yr^{-1} for *C. pseudogracilis*. No biomass estimate was determined for *C. pseudogracilis*, but maximal and actual annual ash-free dry weight biomass estimates for *Gammarus* spp. were 50.8 kg yr^{-1} and 32.1 kg yr^{-1}, respectively. As a good annual benthic gammarid density estimate was not available from the riprap from which the gammarids originated, the effect of entrainment was based on the

October entrainment rate (0.2005 m^{-3}) and the average October benthic density of 139 Gammarus spp. m^{-2}.

In the riprap area, which is equivalent to 52,400 m^2, 7.28×10^6 Gammarus spp. were potentially entrainable during October. Using the maximal pumping rate at Unit 3 and the October entrainment density, an average 3.54×10^5 Gammarus spp. were entrained daily at the Campbell Plant in October. This estimate corresponded to 4.9% of the available riprap population. Using the actual daily pumping rate at Unit 3 in October (94.8×10^5 m^3 day^{-1}), 1.90×10^5 Gammarus spp. were entrained, or 2.6% of the total available riprap population.

Although C. pseudogracilis averaged 0.1306 m^{-3} in October entrainment samples, none were observed on artificial substrates. The lack of Crangonyx on the artificial substrates and its abundance in entrainment samples suggested the artificial substrates may have been a poor substrate for Crangonyx to colonize, possibly due to physical location on the riprap or inability to support suitable food sources. Nevertheless, the large numbers of C. pseudogracilis entrained on an annual basis (8.76×10^7 yr^{-1}) and its very poor representation in net and sled tow samples make it highly unlikely that entrained Crangonyx originate from some other portion of the survey area outside the riprap area. Rather, a population nearly equivalent to that of Gammarus spp. must reside on the riprap which was most certainly the source of entrained C. pseudogracilis.

We concluded that artificial substrates did not adequately estimate the population densities of the gammarids encountered on the riprap. This conclusion was reasonable for *Gammarus* spp. because within a short time, the daily entrainment rate for *Gammarus* spp. would deplete the estimated riprap population density of *Gammarus* spp. to near zero at a declining exponential rate. Despite high entrainment densities, absence of *C. pseudogracilis* on artificial substrates suggested the artificial substrates did not adequately estimate the *Crangonyx* population occurring on the riprap.

Hyalella azteca and *Asellus* sp.--

Occurrence of *H. azteca* was limited to only a few individuals in net tows, sled tows, and entrainment samples. No specimens of *H. azteca* were found in riprap or Ponar grab samples. Averaging only 0.0011 m^{-3} in entrainment samples, the maximal annual entrainment estimate was 7.09×10^5 yr^{-1}. The actual entrainment estimate of *Hyalella* was 4.48×10^5 yr^{-1}. From these data it is apparent that conditions in the survey area did not favor establishment of a dominant population on the riprap, at least in comparison with the gammarid population. A similar situation was observed at the Cook Plant where *H. azteca* averaged only 0.0008 m^{-3} in entrainment samples (unpublished data, GLRD).

Abundance of entrained *Asellus* sp. was 0.0037 m^{-3}, which was equivalent to a maximal annual entrained density

of 2.38 x 10^6 individuals. The actual annual entrained density for asellids was 1.51 x 10^6 individuals. Entrainment of Asellus at the Cook Plant averaged slightly lower (0.0017 m^{-3}) than the present estimate at the Campbell Plant. Asellids did not occur in net tows and were extremely rare in sled tows (0.0001 m^{-3}) at the Campbell Plant.

As asellids are cryptic and remain at or very near the substrate on which they occur, poor representation in net, sled, and entrainment samples was not unexpected. The presence of asellids in Ponar grabs, which sampled sandy substrates, was limited to only rare occurrences in the inner region near the riprap.

Asellus sp. was the most abundant malacostracan colonizing the artificial substrates (313 m^{-2}). Average asellid abundance on the riprap during October was equivalent to 1.64 x 10^7 individuals. When compared with the number maximally entrained in October [(1.766 x 10^6 m^3 day^{-1})(3.079 x 10^{-4} individuals m^{-3}) = 5.44 x 10^2 individuals daily], maximal daily entrainment represented only 0.003% of the asellid population occurring on the riprap. The very low numbers entrained underscore the cryptic nature of asellids and that they are not as pelagic as other malacostracans encountered at the Campbell Plant, thereby reducing their susceptibility to intense entrainment.

SUMMARY

Macrobenthic invertebrates were collected from Ponar grab samples taken in the 3- to 15-m depth regime during April, July, and October 1978 through 1981 near the J.H. Campbell Plant, located along the eastern shoreline of Lake Michigan. In addition, from April through September 1981, malacostracans were enumerated in net and sled tow samples collected from vertical depth strata (net) and near bottom (sled) at stations ranging from 1 to 15 m in depth. Malacostracans occurring in entrainment samples were also enumerated from January through December 1981. Finally, density was determined for macroinvertebrates collected from artificial substrates lodged in the riprap during July 1981 and retrieved during October 1981. These data provided the information from which we were able to determine the effect of discharged heated effluent and entrainment on various major constituents of the macroinvertebrate community common to the Lake Michigan benthic environment near the Campbell Plant.

An analysis of variance (ANOVA) was performed on each of the nine major macroinvertebrate constituents of the benthic community, plus total benthos. In order of decreasing numerical importance in the survey area, the nine most numerous macroinvertebrates were: *Pontoporeia hoyi*, Chironomidae, Naididae, Tubificidae, *Pisidium*, Turbellaria, *Stylodrilus heringianus*, Enchytraeidae, and Gastropoda.

Effect due to discharge of heated effluent was determined by comparing R (least detectable true difference; calculated using ANOVA mean square error) with R' (actual abundance change ratio; calculated from averaged regional log densities before and after plant operation) (see METHODS for detail). Based on this comparison for each taxon, we determined no detectable effect due to heated effluent discharge was attributable to density fluctuations observed among the 10 groups tested. Therefore, we have concluded that operation of the Campbell Plant through 1981, with subsequent offshore discharge of heated effluent, has had either no effect or no detectable effect on those individual portions of the macrobenthic community comprising over 99% of the total benthic density or on the total benthic density, regardless of regional or annual density differences noted from 1978 through 1981.

Numerically, the malacostracan most often entrained was P. hoyi; followed in decreasing numerical order by Gammarus spp. (G. fasciatus and G. pseudolimnaeus), Crangonyx pseudogracilis, Mysis relicta, Asellus sp., and Hyalella azteca. On an annual basis, maximal and actual (as determined from maximum and actual daily pumping rates at the Campbell Plant) entrainment of P. hoyi was 1.17×10^{9} yr^{-1} (820 kg yr^{-1}, ash-free dry weight) and 7.36×10^{8} yr^{-1} (518 kg yr^{-1}, ash-free dry weight), respectively. Similar values for M. relicta were 4.44×10^{7} yr^{-1} (19.1 kg yr^{1}, dry weight) (maximal) or 2.80×10^{7} yr^{-1} (12.0 kg yr^{-1}, dry

weight) (actual). When comparison between entrainment sample and net tow sample densities was made from similar depths and months during which samples were collected using both methods, very similar densities between the two methods for both taxa were observed, indicating entrainment samples were very representative of the pelagic, nearshore densities. This trend provided assurance that annual densities of entrained organisms were relatively unbiased and reasonably accurate estimates of the densities of lake organisms potentially entrainable.

Likely the most important comparison using entrainment data was that between number annually entrained and number potentially available in a 2-km^2 area. For _P. hoyi_ the number potentially entrainable was equivalent to 1.54×10^{10} individuals. Based on the ratio noted above, at most 7.6% of the _P. hoyi_ population was entrained during any average time period. As the population is very mobile, the effect of entrainment on _P. hoyi_ was considered negligible, with the possible exception of an unknown effect due to heavy entrainment of males during winter reproductive activity in December and January.

The effect of entrainment on _M. relicta_ was also negligible due to the high number of mysids potentially available from the vast profundal area of Lake Michigan immediately offshore from the Campbell Plant. Estimating an average mysid density of only 188 m^{-2} (Morgan and Beeton 1978) from the offshore in a 2-km^2 area and assuming all are

potentially entrainable via onshore migration, maximally only 5.9% of these mysids would be entrained annually. However, as with P. hoyi, little is known about the effect of entraining large numbers of males during winter reproductive activity.

Remaining malacostracan taxa in samples collected near the Campbell Plant originated nearly exclusively on the riprap surrounding intake and discharge structures. Although entrained Gammarus spp. and C. pseudogracilis occurred in very similar densities, the latter species was not found on artificial substrates. High densities of C. pseudogracilis in entrainment samples and low to no abundance in all samples from remaining collection methods left little doubt that their origin was the riprap area. Of the two remaining malacostracans encountered, neither Asellus sp. nor H. azteca were entrained in high abundance. While the latter species did not occur on artificial substrates, the former was the most numerous malacostracan on these same substrates. The effect of entrainment on asellids was very minimal (0.003% of the riprap population) and was likely due to the clambering nature of Asellus sp. as opposed to the swimming nature of other malacostracans encountered; susceptibility of asellid to entrainment was thus reduced substantially.

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Appendix 1. Mean densities (no. m^{-2}) for *P. hoyi*, miscellaneous taxa, and total benthos collected during April, July, and October 1981 in the inner (treatment) and outer (reference) regions at 3-15-m depths ($n = 6$) near the J.H. Campbell Plant, eastern Lake Michigan. In addition to mean ($\bar{X}$) and standard error (SE), size classes of *P. hoyi* and turbellarian species in each region have been expressed as percentages of total *P. hoyi* and total turbellarians, respectively.

	April											
	3 m						6 m					
	Inner region			Outer region			Inner region			Outer region		
Taxon	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total *Pontoporeia hoyi*												
P. hoyi <3 mm												
P. hoyi 3-5 mm												
P. hoyi 5-7 mm												
P. hoyi >7 mm												
P. hoyi gravid												
P. hoyi spent												
Miscellaneous taxa	91	51	-	1414	637	-	323	145	-			
Turbellaria	91	51	-	1394	638	-	313	147	-			
Turbellarian sp.1	51	51	55.6	1394	638	100.0	30	14	9.7			
Turbellarian sp.2	40	30	44.4				283	140	90.3			
Turbellarian sp.3												
Turbellarian sp.4												
Hydra sp.				20	20	-						
Gammarus sp.												
Mysis relicta sp.												
Asellus sp.												
Hydracarina							10	10	-			
Other Insecta												
Total benthos	303	118	-	2828	882	-	3060	349	-	3868	538	-

Appendix 1. Continued.

Taxon	April											
	9 m						12 m					
	Inner region			Outer region			Inner region			Outer region		
	X̄	SE	%	X̄	SE	%	X̄	SE	%	X̄	SE	%
Total _Pontoporeia_ _hoyi_	6121	1273	-	1586	591	-	3434	1127	-	2626	766	-
_P_. _hoyi_ <3 mm	5909	1232	96.5	1515	570	95.5	3262	1085	95.0	2374	747	90.4
_P_. _hoyi_ 3-5 mm												
_P_. _hoyi_ 5-7 mm				10	10	0.6	10	10	0.3	10	10	0.4
_P_. _hoyi_ >7 mm										10	10	0.4
_P_. _hoyi_ gravid				10	10	0.6	10	10	0.3	61	49	2.3
_P_. _hoyi_ spent	212	46	3.5	51	24	3.2	152	38	4.4	172	40	6.5
Miscellaneous taxa	323	95	-	121	68	-	10	10	-	192	59	-
Turbellaria	253	59	-	121	68	-				192	59	-
Turbellarian sp.1	30	21	12.0									
Turbellarian sp.2	222	66	88.0	121	68	100.0				192	59	100.0
Turbellarian sp.3												
Turbellarian sp.4												
Hydra sp.	30	21	-				10	10	-			
Gammarus sp.	20	20	-									
Mysis _relicta_ sp.												
Asellus sp.												
Hydracarina	10	10	-									
Other Insecta	10	10	-									
Total benthos	9706	1342	-	5909	1257	-	4656	1277	-	6080	1266	-

Appendix 1. Continued.

	April											
	15 m						All depths combined					
	Inner region			Outer region			Inner region			Outer region		
Taxon	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total *Pontoporeia hoyi*	11231	1191	-	7080	1443	-	4157	873	-	2258	582	-
P. hoyi <3 mm	9918	1218	88.3	6100	1370	86.2	3818	796	91.8	1998	519	88.5
P. hoyi 3-5 mm				20	13	0.3				4	3	0.2
P. hoyi 5-7 mm	212	66	1.9	192	43	2.7	44	20	1.1	42	16	1.9
P. hoyi >7 mm	30	21	0.3				6	5	0.1	2	2	0.1
P. hoyi gravid	212	178	1.9	20	20	0.3	44	37	1.1	18	11	0.8
P. hoyi spent	858	243	7.6	747	108	10.6	244	63	5.9	194	57	8.6
Miscellaneous taxa	20	13	-	293	93	-	154	43	-	404	154	-
Turbellaria	10	10	-	273	85	-	133	39	-	396	153	-
Turbellarian sp.1							22	11	16.7	279	157	70.4
Turbellarian sp.2	10	10	100.0	263	87	96.3	111	37	83.3	115	30	29.1
Turbellarian sp.3				10	10	3.7				2	2	0.5
Turbellarian sp.4												
Hydra sp.							8	5	-	4	4	-
Gammarus sp.							4	4	-			
Mysis relicta sp.				10	10	-				2	2	-
Asellus sp.												
Hydracarina				10	10	-	4	3	-	2	2	-
Other Insecta	10	10	-				4	3	-			
Total benthos	14786	1649	-	11585	1913	-	6502	1064	-	6054	767	-

Appendix 1. Continued.

Taxon	July: 3 m Inner region $\bar{X}$	SE	%	3 m Outer region $\bar{X}$	SE	%	6 m Inner region $\bar{X}$	SE	%	6 m Outer region $\bar{X}$	SE	%
Total *Pontoporeia hoyi*				40	30	-	51	33	-	40	13	-
P. hoyi <3 mm							20	13	40.0	10	10	25.0
P. hoyi 3-5 mm				40	30	100.0	30	21	60.0	30	14	75.0
P. hoyi 5-7 mm												
P. hoyi >7 mm												
P. hoyi gravid												
P. hoyi spent												
Miscellaneous taxa	323	185	-	1677	317	-	111	36	-	61	41	-
Turbellaria	293	189	-	1677	317	-	101	40	-	61	41	-
Turbellarian sp.1	263	194	89.7	1667	309	99.4	20	20	20.0	20	13	33.3
Turbellarian sp.2	30	14	10.3	10	10	0.6	81	30	80.0	10	10	16.7
Turbellarian sp.3												
Turbellarian sp.4										30	30	50.0
Hydra sp.	20	20	-				10	10	-			
Gammarus sp.	10	10	-									
Mysis relicta sp.												
Asellus sp.												
Hydracarina												
Other Insecta												
Total benthos	5131	1417	-	4484	449	-	10090	2247	-	4777	357	-

Appendix 1. Continued.

Taxon	July											
	9 m						12 m					
	Inner region			Outer region			Inner region			Outer region		
	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total *Pontoporeia hoyi*	1212	126	-	1505	123	-	11908	1189	-	7484	396	-
P. hoyi <3 mm	61	27	5.0	10	10	0.7	788	180	6.6	162	20	2.2
P. hoyi 3-5 mm	1151	139	95.0	1495	127	99.3	11100	1033	93.2	7302	389	97.6
P. hoyi 5-7 mm							20	13	0.2	20	13	0.3
P. hoyi >7 mm												
P. hoyi gravid												
P. hoyi spent												
Miscellaneous taxa	303	107	-	253	53	-	1020	133	-	1737	168	-
Turbellaria	172	86	-	253	53	-	1000	134	-	1707	166	-
Turbellarian sp.1	81	60	47.1				20	13	2.0			
Turbellarian sp.2	71	29	41.2	202	56	80.0	949	125	94.9	1444	125	84.5
Turbellarian sp.3	20	13	11.8				10	10	1.0	30	14	1.8
Turbellarian sp.4				51	19	20.0	20	20	2.0	232	65	13.6
Hydra sp.							10	10	-	20	20	-
Gammarus sp.	10	10	-									
Mysis relicta sp.										10	10	-
Asellus sp.	121	75	-				10	10	-			
Hydracarina												
Other Insecta												
Total benthos	11433	1870	-	11534	842	-	21513	1625	-	21099	2005	-

Appendix 1. Continued.

Taxon	July 15 m Inner region $\bar{X}$	SE	%	15 m Outer region $\bar{X}$	SE	%	All depths combined Inner region $\bar{X}$	SE	%	All depths combined Outer region $\bar{X}$	SE	%
Total *Pontoporeia hoyi*	17321	2479	-	16604	1893	-	6098	1427	-	5135	1234	-
P. hoyi <3 mm	3363	422	19.4	3424	624	20.6	846	255	13.9	721	277	14.0
P. hoyi 3-5 mm	13898	2107	80.2	13049	1377	78.6	5236	1198	85.9	4383	983	85.4
P. hoyi 5-7 mm	51	40	0.3	121	27	0.7	14	9	0.2	28	10	0.6
P. hoyi >7 mm	10	10	0.1	10	10	0.1	2	2	<0.1	2	2	<0.1
P. hoyi gravid												
P. hoyi spent												
Miscellaneous taxa	1000	132	-	1050	189	-	551	89	-	955	150	-
Turbellaria	960	145	-	1030	179	-	505	91	-	945	149	-
Turbellarian sp.1							77	42	15.2	337	136	35.7
Turbellarian sp.2	788	126	82.1	960	171	93.1	384	82	76.0	525	115	55.6
Turbellarian sp.3	30	14	3.2				12	5	2.4	6	3	0.6
Turbellarian sp.4	141	46	14.7	71	24	6.9	32	14	6.4	77	21	8.1
Hydra sp.	30	21	-	10	10	-	14	6	-	6	5	-
Gammarus sp.							4	3	-			
Mysis relicta sp.										2	2	-
Asellus sp.							26	17	-			-
Hydracarina	10	10	-	10	10	-	2	2	-	2	2	-
Other Insecta												
Total benthos	31764	5311	-	31259	3918	-	15986	2133	-	14631	2084	-

Appendix 1. Continued.

Taxon	October											
	3 m						6 m					
	Inner region			Outer region			Inner region			Outer region		
	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total *Pontoporeia hoyi*				40	13	-	10	10	-	172	29	-
P. hoyi <3 mm										40	30	23.5
P. hoyi 3-5 mm				40	13	100.0	10	10	100.0	81	13	47.1
P. hoyi 5-7 mm										51	19	29.4
P. hoyi >7 mm												
P. hoyi gravid												
P. hoyi spent												
Miscellaneous taxa	71	40	-	1283	409	-	182	56	-	273	56	-
Turbellaria	71	40	-	1212	401	-	172	57	-	242	66	-
Turbellarian sp.1	71	40	100.0	1212	401	100.0	162	58	94.1	10	10	4.2
Turbellarian sp.2							10	10	5.9	212	64	87.5
Turbellarian sp.3												
Turbellarian sp.4										20	20	8.3
Hydra sp.												
Gammarus sp.												
Mysis relicta sp.												
Asellus sp.												
Hydracarina										20	13	-
Other Insecta				71	45	-	10	10	-	10	10	-
Total benthos	101	37	-	1515	419	-	1525	593	-	9019	1017	-

Appendix 1. Continued.

Taxon	October											
	9 m						12 m					
	Inner region			Outer region			Inner region			Outer region		
	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total *Pontoporeia hoyi*	545	65	-	485	108	-	1343	357	-	1576	239	-
P. hoyi <3 mm												
P. hoyi 3-5 mm	404	58	74.1	323	74	66.7	1071	281	79.7	1172	186	74.4
P. hoyi 5-7 mm	141	37	25.9	162	51	33.3	273	88	20.3	404	64	25.6
P. hoyi >7 mm												
P. hoyi gravid												
P. hoyi spent												
Miscellaneous taxa	232	67	-	586	382	-	121	35	-	293	72	-
Turbellaria	222	60	-	283	96	-	121	35	-	283	68	-
Turbellarian sp.1	10	10	4.5	10	10	3.6	20	20	16.7			
Turbellarian sp.2	182	44	81.8	263	78	92.9	91	30	75.0	212	60	75.0
Turbellarian sp.3	20	20	9.1									
Turbellarian sp.4	10	10	4.5	10	10	3.6	10	10	8.3	71	29	25.0
Hydra sp.				303	291	-						
Gammarus sp.												
Mysis relicta sp.												
Asellus sp.												
Hydracarina												
Other Insecta	10	10	-							10	10	-
Total benthos	5474	1185	-	10039	1077	-	5656	737	-	11322	942	-

Appendix 1. Continued.

	October											
	15 m						All depths combined					
	Inner region			Outer region			Inner region			Outer region		
Taxon	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total *Pontoporeia hoyi*	4555	519	-	7009	1369	-	1291	338	-	1856	553	-
P. hoyi <3 mm	20	13	0.4	131	65	1.9	4	3	0.3	34	16	1.8
P. hoyi 3-5 mm	3818	482	83.8	6444	1264	91.9	1061	286	82.2	1612	513	86.8
P. hoyi 5-7 mm	717	82	15.7	333	108	4.8	226	55	17.5	190	39	10.2
P. hoyi >7 mm				101	30	1.4				20	9	1.1
P. hoyi gravid												
P. hoyi spent												
Miscellaneous taxa	232	71	-	535	180	-	168	26	-	594	130	-
Turbellaria	232	71	-	505	184	-	164	25	-	505	109	-
Turbellarian sp.1	30	14	13.0				59	17	35.8	246	116	48.8
Turbellarian sp.2	182	63	78.3	330	134	66.0	93	21	56.8	204	39	40.4
Turbellarian sp.3							4	4	2.5			
Turbellarian sp.4	20	13	8.7	172	101	34.0	8	4	4.9	55	23	10.8
Hydra sp.										61	59	-
Gammarus sp.												
Mysis relicta sp.				20	13	-				4	3	-
Asellus sp.												
Hydracarina										4	3	-
Other Insecta				10	10	-	4	3	-	20	10	-
Total benthos	14140	1376	-	16776	3182	-	5379	984	-	9734	1136	-

Appendix 2. Mean densities (no. m^{-2}) for chironomid taxa collected during April, July, and October 1981 in the inner (treatment) and outer (reference) regions at 3-15-m depths (n = 6) near the J.H. Campbell Plant, eastern Lake Michigan. In addition to mean ($\bar{X}$) and standard error (SE), chironomid taxa in each region have been expressed as a percentage of total chironomids.

	April											
	3 m						6 m					
	Inner region			Outer region			Inner region			Outer region		
Taxon	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total Chironomidae	212	71	-	1414	712	-	2697	309	-	3767	520	-
Chironomus spp.												
Chironomus fluviatilis-gr.							354	74	13.1	111	29	2.9
Cladopelma sp.												
Cryptochironomus sp.1												
Cryptochironomus sp.2							30	21	1.1	30	21	0.8
Cryptochironomus sp.3												
Cryptochironomus cf. rolli	10	10	4.8	20	13	1.4	71	33	2.6	71	29	1.9
Glyptotendipes (P.) sp.												
Harnischia sp.												
Microtendipes sp.												
Parachironomus cf. abortivus				10	10	0.7						
Parachironomus sp.1												
Paracladopelma cf. undine												
Paracladopelma camptolabis-gr.	30	14	14.3	30	14	2.1	677	91	25.1	566	114	15.0
Paracladopelma cf. winnelli										10	10	0.3
Paratendipes sp.												
Polypedilum cf. halterale												
Polypedilum cf. illinoense												
Polypedilum cf. simulans/digitifer							10	10	0.4	10	10	0.3
Polypedilum cf. scalaenum							30	21	1.1	10	10	0.3
Polypedilum cf. tuberculum												
Robackia cf. demeijerei	61	31	28.6	1212	690	85.7	20	20	0.7	40	20	1.1
Saetheria cf. tylus	91	41	42.9	101	34	7.1	1434	294	53.2	2798	400	74.3
Cladotanytarsus sp.							40	20	1.5	20	20	0.5
Micropsectra sp												
Cricotopus (C.) tremulus-gr.				10	10	0.7						
Cricotopus (I.) cf. intersectus												
Cricotopus (I.) cf. suspiciosus												
Cricotopus (I.) sp												
Heterotrissocladius cf. changi												
Hydrobaenus sp.												
Orthocladius (O.) sp.										10	10	0.3
Parakiefferiella sp.	20	13	9.5	30	21	2.1	10	10	0.4	91	58	2.4
Psectrocladius cf. simulans												
Monodiamesa cf. tuberculata							10	10	0.4			
Potthastia cf. longimanus												
Procladius sp.												
Thiennemannymia-gr.												
Other							10	10	0.4			

Appendix 2. Continued.

Taxon	April											
	9 m						12 m					
	Inner region			Outer region			Inner region			Outer region		
	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total Chironomidae	1949	179	-	1747	335	-	566	76	-	374	43	-
Chironomus spp.												
Chironomus fluviatilis-gr.	232	67	11.9	101	46	5.8	51	29	8.9	20	13	5.4
Cladopelma sp.												
Cryptochironomus sp.1												
Cryptochironomus sp.2	162	40	8.3	172	61	9.8	51	24	8.9	71	29	18.9
Cryptochironomus sp.3							10	10	1.8			
Cryptochironomus cf. rolli	40	20	2.1	10	10	0.6	10	10	1.8			
Glyptotendipes (P.) sp.												
Harnischia sp.												
Microtendipes sp.												
Parachironomus cf. abortivus												
Parachironomus sp.1												
Paracladopelma cf. undine	10	10	0.5									
Paracladopelma camptolabis-gr.	1030	138	52.8	879	203	50.3	273	44	48.2	131	36	35.1
Paracladopelma cf. winnelli												
Paratendipes sp.												
Polypedilum cf. halterale												
Polypedilum cf. illinoense												
Polypedilum cf. simulans/digitifer				10	10	0.6						
Polypedilum cf. scalaenum	172	48	8.8	192	63	11.0	10	10	1.8			
Polypedilum cf. tuberculum	20	13	1.0									
Robackia cf. demeijerei	10	10	0.5									
Saetheria cf. tylus	152	38	7.8	152	46	8.7	141	30	25.0	81	26	21.6
Cladotanytarsus sp.	91	34	4.7	152	46	8.7						
Micropsectra sp												
Cricotopus (C.) tremulus-gr.												
Cricotopus (I.) cf. intersectus												
Cricotopus (I.) cf. suspiciosus												
Cricotopus (I.) sp												
Heterotrissocladius cf. changi	10	10	0.5				20	13	3.6	30	21	8.1
Hydrobaenus sp.				20	13	1.2				30	14	8.1
Orthocladius (O.) sp.												
Parakiefferiella sp.				30	14	1.7				10	10	2.7
Psectrocladius cf. simulans				10	10	0.6						
Monodiamesa cf. tuberculata	20	13	1.0	20	13	1.2						
Potthastia cf. longimanus												
Procladius sp.												
Thiennemannymia-gr.												
Other												

Appendix 2. Continued.

Taxon	April											
	15 m						All depths combined					
	Inner region			Outer region			Inner region			Outer region		
	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total Chironomidae	404	43	-	455	92	-	1166	195	-	1551	288	-
Chironomus spp.												
Chironomus fluviatilis-gr.	10	10	2.5				129	32	11.1	46	14	3.0
Cladopelma sp.												
Cryptochironomus sp.1												
Cryptochironomus sp.2	30	14	7.5	20	13	4.4	55	14	4.7	59	18	3.8
Cryptochironomus sp.3							2	2	0.2			
Cryptochironomus cf. *rolli*							26	9	2.3	20	8	1.3
Glyptotendipes (*P.*) sp.												
Harnischia sp.												
Microtendipes sp.												
Parachironomus cf. *abortivus*										2	2	0.1
Parachironomus sp.1												
Paracladopelma cf. *undine*	10	10	2.5				4	3	0.3			
Paracladopelma camptolabis-gr.				20	13	4.4	402	80	34.5	325	77	21.0
Paracladopelma cf. *winnelli*				10	10	2.2				4	3	0.3
Paratendipes sp.												
Polypedilum cf. *halterale*												
Polypedilum cf. *illinoense*												
Polypedilum cf. *simulans/digitifer*							2	2	0.2	4	3	0.3
Polypedilum cf. *scalaenum*	10	10	2.5	10	10	2.2	44	16	3.8	42	18	2.7
Polypedilum cf. *tuberculum*	121	22	30.0	152	26	33.3	28	10	2.4	30	12	2.0
Robackia cf. *demeijerei*							18	8	1.6	250	156	16.1
Saetheria cf. *tylus*	81	13	20.0	71	19	15.6	380	113	32.6	640	214	41.3
Cladotanytarsus sp.							26	10	2.3	34	14	2.2
Micropsectra sp												
Cricotopus (*C.*) *tremulus*-gr.										2	2	0.1
Cricotopus (*I.*) cf. *intersectus*												
Cricotopus (*I.*) cf. *suspiciosus*												
Cricotopus (*I.*) sp												
Heterotrissocladius cf. *changi*	61	31	15.0	121	49	26.7	18	8	1.6	30	13	2.0
Hydrobaenus sp.	51	19	12.5				10	5	0.9	10	4	0.7
Orthocladius (*O.*) sp.										2	2	0.1
Parakiefferiella sp.							6	3	0.5	32	13	2.1
Psectrocladius cf. *simulans*										2	2	0.1
Monodiamesa cf. *tuberculata*	20	13	5.0	51	24	11.1	10	4	0.9	14	6	0.9
Potthastia cf. *longimanus*												
Procladius sp.												
Thiennemannymia-gr.												
Other	10	10	2.5				4	3	0.3			

Appendix 2. Continued.

Taxon	July											
	3 m						6 m					
	Inner region			Outer region			Inner region			Outer region		
	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total Chironomidae	4050	1029	-	2757	412	-	4818	1248	-	3394	312	-
Chironomus spp.	131	55	3.2	10	10	0.4	1242	1005	25.8	51	29	1.5
Chironomus fluviatilis-gr.	20	20	0.5	10	10	0.4	263	85	5.5	202	62	6.0
Cladopelma sp.												
Cryptochironomus sp.1	131	51	3.2	515	38	18.7				61	16	1.8
Cryptochironomus sp.2							81	26	1.7	101	13	3.0
Cryptochironomus sp.3	30	14	0.7	30	21	1.1				10	10	0.3
Cryptochironomus cf. *rolli*	131	71	3.2	111	36	4.0				10	10	0.3
Glyptotendipes (*P.*) sp.												
Harnischia sp.												
Microtendipes sp.							10	10	0.2			
Parachironomus cf. *abortivus*												
Parachironomus sp.1	10	10	0.2									
Paracladopelma cf. *undine*	20	13	0.5				343	85	7.1	354	79	10.4
Paracladopelma camptolabis-gr.	30	21	0.7				81	40	1.7	111	29	3.3
Paracladopelma cf. *winnelli*												
Paratendipes sp.							20	20	0.4			
Polypedilum cf. *halterale*												
Polypedilum cf. *illinoense*												
Polypedilum cf. *simulans/digitifer*												
Polypedilum cf. *scalaenum*							20	13	0.4			
Polypedilum cf. *tuberculum*												
Robackia cf. *demeijerei*	1010	228	24.9	626	125	22.7	1434	522	29.8	960	167	28.3
Saetheria cf. *tylus*	1414	252	34.9	1414	322	51.3	818	97	17.0	1505	226	44.3
Cladotanytarsus sp.							61	49	1.3			
Micropsectra sp	10	10	0.2				81	81	1.7			
Cricotopus (*C.*) *tremulus*-gr.												
Cricotopus (*I.*) cf. *intersectus*												
Cricotopus (*I.*) cf. *suspiciosus*	10	10	0.2									
Cricotopus (*I.*) sp				10	10	0.4						
Heterotrissocladius cf. *changi*							81	81	1.7			
Hydrobaenus sp.												
Orthocladius (*O.*) sp.										10	10	0.3
Parakiefferiella sp.	20	20	0.5	10	10	0.4	111	89	2.3			
Psectrocladius cf. *simulans*	1081	887	26.7	20	20	0.7	121	66	2.5	20	13	0.6
Monodiamesa cf. *tuberculata*							40	20	0.8			
Potthastia cf. *longimanus*							10	10	0.2			
Procladius sp.												
Thiennemannymia-gr.												
Other												

Appendix 2. Continued.

Taxon	July 9 m Inner region $\bar{X}$	SE	%	9 m Outer region $\bar{X}$	SE	%	12 m Inner region $\bar{X}$	SE	%	12 m Outer region $\bar{X}$	SE	%
Total Chironomidae	2727	420	-	2232	177	-	818	87	-	1364	325	-
Chironomus spp.	10	10	0.4				40	20	4.9			
Chironomus fluviatilis-gr.	182	98	6.7	141	58	6.3	182	41	22.2	394	105	28.9
Cladopelma sp.												
Cryptochironomus sp.1												
Cryptochironomus sp.2	212	46	7.8	91	26	4.1	40	13	4.9	101	37	7.4
Cryptochironomus sp.3				10	10	0.5				10	10	0.7
Cryptochironomus cf. rolli				10	10	0.5						
Glyptotendipes (P.) sp.												
Harnischia sp.	10	10	0.4									
Microtendipes sp.	20	13	0.7	10	10	0.5				10	10	0.7
Parachironomus cf. abortivus												
Parachironomus sp.1												
Paracladopelma cf. undine	313	55	11.5	253	36	11.3				61	27	4.4
Paracladopelma camptolabis-gr.	232	53	8.5	222	56	10.0	20	13	2.5	81	20	5.9
Paracladopelma cf. winnelli	51	19	1.9				20	13	2.5	30	14	2.2
Paratendipes sp.	20	13	0.7									
Polypedilum cf. halterale	10	10	0.4									
Polypedilum cf. illinoense												
Polypedilum cf. simulans/digitifer	10	10	0.4	10	10	0.5						
Polypedilum cf. scalaenum	131	36	4.8	61	22	2.7	40	20	4.9	40	20	3.0
Polypedilum cf. tuberculum												
Robackia cf. demeijerei	384	106	14.1	838	96	37.6	20	13	2.5	40	20	3.0
Saetheria cf. tylus	354	104	13.0	263	85	11.8	61	27	7.4	10	10	0.7
Cladotanytarsus sp.	51	19	1.9	61	22	2.7	10	10	1.2			
Micropsectra sp	313	185	11.5	10	10	0.5	172	65	21.0	364	154	26.7
Cricotopus (C.) tremulus-gr.												
Cricotopus (I.) cf. intersectus												
Cricotopus (I.) cf. suspiciosus												
Cricotopus (I.) sp												
Heterotrissocladius cf. changi	192	61	7.0	20	13	0.9	91	38	11.1	101	34	7.4
Hydrobaenus sp.												
Orthocladius (O.) sp.	71	40	2.6	30	14	1.4				10	10	0.7
Parakiefferiella sp.	71	40	2.6	141	84	6.3	10	10	1.2	10	10	0.7
Psectrocladius cf. simulans	30	14	1.1	40	20	1.8	10	10	1.2	10	10	0.7
Monodiamesa cf. tuberculata	40	26	1.5	10	10	0.5	71	24	8.6	61	27	4.4
Potthastia cf. longimanus	20	13	0.7									
Procladius sp.				10	10	0.5	30	14	3.7	30	14	2.2
Thiennemannymia-gr.												
Other												

Appendix 2. Continued.

Taxon	July 15 m Inner region $\bar{X}$	SE	%	15 m Outer region $\bar{X}$	SE	%	All depths combined Inner region $\bar{X}$	SE	%	All depths combined Outer region $\bar{X}$	SE	%
Total Chironomidae	677	174	-	1616	850	-	2618	440	-	2273	240	-
Chironomus spp.				10	10	0.6	285	207	10.9	14	7	0.6
Chironomus fluviatilis-gr.	40	20	6.0	40	20	2.6	137	31	5.2	158	36	6.9
Cladopelma sp.												
Cryptochironomus sp.1							26	14	1.0	115	38	5.1
Cryptochironomus sp.2	40	30	6.0	20	13	1.3	75	18	2.9	63	12	2.8
Cryptochironomus sp.3							6	3	0.2	12	5	0.5
Cryptochironomus cf. rolli							26	16	1.0	26	11	1.2
Glyptotendipes (P.) sp.												
Harnischia sp.							2	2	0.1			
Microtendipes sp.							6	3	0.2	4	3	0.2
Parachironomus cf. abortivus												
Parachironomus sp.1							2	2	0.1			
Paracladopelma cf. undine							135	35	5.2	133	32	5.9
Paracladopelma camptolabis-gr.	20	20	3.0				77	20	2.9	83	20	3.6
Paracladopelma cf. winnelli	10	10	1.5	20	20	1.3	16	6	0.6	10	5	0.4
Paratendipes sp.							8	5	0.3			
Polypedilum cf. halterale							2	2	0.1			
Polypedilum cf. illinoense												
Polypedilum cf. simulans/digitifer							2	2	0.1	2	2	0.1
Polypedilum cf. scalaenum	10	10	1.5				40	12	1.5	20	7	0.9
Polypedilum cf. tuberculum	61	22	9.0	152	56	9.4	12	6	0.5	30	15	1.3
Robackia cf. demeijerei	10	10	1.5				572	150	21.8	493	86	21.7
Saetheria cf. tylus	20	13	3.0				533	111	20.4	638	146	28.1
Cladotanytarsus sp.				10	10	0.6	24	11	0.9	14	6	0.6
Micropsectra sp	283	149	41.8	1273	856	78.8	172	53	6.6	329	186	14.5
Cricotopus (C.) tremulus-gr.												
Cricotopus (I.) cf. intersectus												
Cricotopus (I.) cf. suspiciosus							2	2	0.1			
Cricotopus (I.) sp										2	2	0.1
Heterotrissocladius cf. changi	30	14	4.5	10	10	0.6	79	24	3.0	26	10	1.2
Hydrobaenus sp.												
Orthocladius (O.) sp.				10	10	0.6	14	9	0.5	12	5	0.5
Parakiefferiella sp.							42	20	1.6	32	19	1.4
Psectrocladius cf. simulans	10	10	1.5	20	20	1.3	250	183	9.6	22	7	1.0
Monodiamesa cf. tuberculata	61	16	9.0	40	30	2.5	42	9	1.6	22	9	1.0
Potthastia cf. longimanus	51	29	7.5				16	7	0.6			
Procladius sp.	30	21	4.5	10	10	0.6	12	5	0.5	10	4	0.4
Thiennemannymia-gr.												
Other												

Appendix 2. Continued.

Taxon	October											
	3 m						6 m					
	Inner region			Outer region			Inner region			Outer region		
	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total Chironomidae	30	21	-	131	48	-	1293	563	-	5676	384	-
Chironomus spp.												
Chironomus fluviatilis-gr.										1273	208	22.4
Cladopelma sp.												
Cryptochironomus sp.1												
Cryptochironomus sp.2	10	10	33.3							111	33	2.0
Cryptochironomus sp.3										40	13	0.7
Cryptochironomus cf. rolli										71	40	1.2
Glyptotendipes (P.) sp.												
Harnischia sp.												
Microtendipes sp.												
Parachironomus cf. abortivus												
Parachironomus sp.1												
Paracladopelma cf. undine												
Paracladopelma camptolabis-gr.	10	10	33.3	10	10	7.7				3323	225	58.5
Paracladopelma cf. winnelli												
Paratendipes sp.												
Polypedilum cf. halterale												
Polypedilum cf. illinoense				10	10	7.7						
Polypedilum cf. simulans/digitifer										10	10	0.2
Polypedilum cf. scalaenum										141	51	2.5
Polypedilum cf. tuberculum												
Robackia cf. demeijerei	10	10	33.3	40	13	30.8	354	145	27.3			
Saetheria cf. tylus				61	38	46.2	899	423	69.5	354	53	6.2
Cladotanytarsus sp.							10	10	0.8	242	59	4.3
Micropsectra sp												
Cricotopus (C.) tremulus-gr.												
Cricotopus (I.) cf. intersectus				10	10	0.7						
Cricotopus (I.) cf. suspiciosus												
Cricotopus (I.) sp												
Heterotrissocladius cf. changi										20	13	0.4
Hydrobaenus sp.												
Orthocladius (O.) sp.												
Parakiefferiella sp.							10	10	0.8	51	10	0.9
Psectrocladius cf. simulans												
Monodiamesa cf. tuberculata												
Potthastia cf. longimanus												
Procladius sp.										40	13	0.7
Thiennemannymia-gr.												
Other							20	13	1.6			

Appendix 2. Continued.

	October											
	9 m						12 m					
	Inner region			Outer region			Inner region			Outer region		
Taxon	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total Chironomidae	1343	274	-	3454	482	-	404	79	-	980	103	-
Chironomus spp.												
Chironomus fluviatilis-gr.	495	114	36.8	1172	162	33.9	121	47	30.0	232	48	23.7
Cladopelma sp.							10	10	2.5			
Cryptochironomus sp.1												
Cryptochironomus sp.2	111	53	8.3	101	37	2.9	10	10	2.5	192	65	19.6
Cryptochironomus sp.3												
Cryptochironomus cf. rolli	10	10	0.8	71	10	2.0						
Glyptotendipes (P.) sp.										10	10	1.0
Harnischia sp.												
Microtendipes sp.												
Parachironomus cf. abortivus												
Parachironomus sp.1	10	10	0.8							10	10	1.0
Paracladopelma cf. undine												
Paracladopelma camptolabis-gr.	313	138	23.3	1020	164	29.5	10	10	2.5	121	47	12.4
Paracladopelma cf. winnelli												
Paratendipes sp.												
Polypedilum cf. halterale												
Polypedilum cf. illinoense												
Polypedilum cf. simulans/digitifer												
Polypedilum cf. scalaenum	10	10	0.8	121	27	3.5	10	10	3.5			
Polypedilum cf. tuberculum				20	13	0.6						
Robackia cf. demeijerei	10	10	0.8	10	10	0.3	10	10	2.5			
Saetheria cf. tylus	30	14	2.3	101	20	2.9	172	93	42.5	131	19	13.4
Cladotanytarsus sp.	212	142	15.8	697	191	20.2				10	10	1.0
Micropsectra sp	10	10	0.8									
Cricotopus (C.) tremulus-gr.												
Cricotopus (I.) cf. intersectus												
Cricotopus (I.) cf. suspiciosus												
Cricotopus (I.) sp												
Heterotrissocladius cf. changi	20	20	1.5	10	10	0.3	40	13	10.0	253	76	25.8
Hydrobaenus sp.												
Orthocladius (O.) sp.												
Parakiefferiella sp.	71	51	5.3	91	41	2.6	10	10	2.5			
Psectrocladius cf. simulans												
Monodiamesa cf. tuberculata	10	10	0.8				10	10	2.5	10	10	1.0
Potthastia cf. longimanus										10	10	1.0
Procladius sp.	30	30	2.3	10	10	0.3						
Thiennemannymia-gr.												
Other				30	14	0.9						

Appendix 2. Continued.

Taxon	October, 15 m, Inner region, $\bar{X}$	SE	%	15 m, Outer region, $\bar{X}$	SE	%	All depths combined, Inner region, $\bar{X}$	SE	%	All depths combined, Outer region, $\bar{X}$	SE	%
Total Chironomidae	212	54	-	727	120	-	657	156	-	2194	404	-
Chironomus spp.												
Chironomus fluviatilis-gr.	10	10	4.8	121	52	16.7	125	42	19.1	560	114	25.5
Cladopelma sp.							2	2	0.3			
Cryptochironomus sp.1												
Cryptochironomus sp.2	20	13	9.5	30	14	4.2	30	13	4.6	87	20	4.0
Cryptochironomus sp.3										8	4	0.4
Cryptochironomus cf. rolli							2	2	0.3	28	10	1.3
Glyptotendipes (P.) sp.										2	2	0.1
Harnischia sp.												
Microtendipes sp.												
Parachironomus cf. abortivus												
Parachironomus sp.1							2	2	0.3	2	2	0.1
Paracladopelma cf. undine												
Paracladopelma camptolabis-gr.							67	34	10.2	895	242	40.8
Paracladopelma cf. winnelli												
Paratendipes sp.												
Polypedilum cf. halterale												
Polypedilum cf. illinoense				10	10	1.4				4	3	0.2
Polypedilum cf. simulans/digitifer										2	2	0.1
Polypedilum cf. scalaenum							4	3	0.6	53	16	2.4
Polypedilum cf. tuberculum										4	3	0.2
Robackia cf. demeijerei				10	10	1.4	77	37	11.7	12	5	0.6
Saetheria cf. tylus	61	49	28.6	20	13	2.8	232	103	35.5	133	25	6.1
Cladotanytarsus sp.							44	31	6.8	190	62	8.7
Micropsectra sp							2	2	0.3			
Cricotopus (C.) tremulus-gr.												
Cricotopus (I.) cf. intersectus										2	2	0.1
Cricotopus (I.) cf. suspiciosus												
Cricotopus (I.) sp												
Heterotrissocladius cf. changi	101	37	47.6	333	126	45.8	32	11	4.9	123	38	5.6
Hydrobaenus sp.												
Orthocladius (O.) sp.												
Parakiefferiella sp.							18	11	2.8	28	10	1.3
Psectrocladius cf. simulans												
Monodiamesa cf. tuberculata	10	10	4.8	20	13	2.8	6	3	0.9	6	3	0.3
Potthastia cf. longimanus										2	2	0.1
Procladius sp.	10	10	4.8	172	93	23.6	8	6	1.2	44	21	20
Thienemannymia-gr.				10	10	1.4				2	2	0.1
Other							4	3	0.6	6	3	0.3

Appendix 3. Mean densities (no. m^{-2}) for annelid taxa collected during April, July, and October 1981 in the inner (treatment) and outer (reference) regions at 3-15-m depths (n = 6) near the J.H. Campbell Plant, eastern Lake Michigan. In addition to mean ($\bar{X}$) and standard error (SE), naidid and tubificid taxa in each region have been expressed as a percentage of total naidids and total tubificids, respectively.

	April											
	3 m						6 m					
	Inner region			Outer region			Inner region			Outer region		
Taxon	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total Naididae							10	10	-	51	29	-
Amphichaeta leydigii												
Chaetogaster diaphanus												
Chaetogaster diastrophus												
Dero digitata												
Dero pectinata												
Nais barbata												
Nais behningi												
Nais communis												
Nais pardalis												
Nais simplex												
Nais variabilis												
Piguetiella michiganensis							10	10	100.0	30	21	60.0
Stylaria lacustris												
Uncinais uncinata										10	10	20.0
Vejdovskyella intermedia										10	10	20.0
Total Tubificidae							30	14	-	40	13	-
Immatures without hair chaeta							30	14	100.0	40	13	100.0
Immatures with hair chaeta												
Aulodrilus pigueti												
Limnodrilus angustipenis												
Limnodrilus hoffmeisteri												
Limnodrilus profundicola												
Limnodrilus spiralis												
Peloscolex freyi												
Peloscolex multisetosus longidentus												
Potamothrix moldaviensis												
Potamothrix vejdovskyi												
Stylodrilus heringianus												
Enchytraeidae												
Hirudinea												

Appendix 3. Continued.

Taxon	April 9 m Inner region $\bar{X}$	SE	%	9 m Outer region $\bar{X}$	SE	%	12 m Inner region $\bar{X}$	SE	%	12 m Outer region $\bar{X}$	SE	%
Total Naididae	172	80	-	172	57	-	101	89	-	111	88	-
Amphichaeta leydigii												
Chaetogaster diaphanus												
Chaetogaster diastrophus												
Dero digitata												
Dero pectinata												
Nais barbata												
Nais behningi												
Nais communis												
Nais pardalis												
Nais simplex												
Nais variabilis										10	10	9.1
Piguetiella michiganensis	162	74	94.1	172	57	100.0	101	89	100.0	101	89	90.9
Stylaria lacustris												
Uncinais uncinata	10	10	5.9									
Vejdovskyella intermedia												
Total Tubificidae	1061	361	-	2101	436	-	333	162	-	1959	714	-
Immatures without hair chaeta	990	331	93.3	1869	368	88.9	323	154	97.0	1879	690	95.9
Immatures with hair chaeta												
Aulodrilus pigueti												
Limnodrilus angustipenis												
Limnodrilus hoffmeisteri	20	13	1.9	71	36	3.4				20	13	1.0
Limnodrilus profundicola												
Limnodrilus spiralis	30	21	2.9	51	33	2.4				10	10	0.5
Peloscolex freyi	10	10	1.0	20	13	1.0						
Peloscolex multisetosus longidentus												
Potamothrix moldaviensis	10	10	1.0	91	68	4.3	10	10	3.0	51	24	2.6
Potamothrix vejdovskyi												
Stylodrilus heringianus												
Enchytraeidae	20	13	-	71	40	-				152	78	-
Hirudinea												

Appendix 3. Continued.

	April											
	15 m						All depths combined					
	Inner region			Outer region			Inner region			Outer region		
Taxon	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total Naididae	51	24	-	81	30	-	67	26	-	83	24	-
Amphichaeta leydigii				10	10	12.5				2	2	2.4
Chaetogaster diaphanus												
Chaetogaster diastrophus												
Dero digitata												
Dero pectinata												
Nais barbata												
Nais behningi												
Nais communis	10	10	20.0				2	2	3.0			
Nais pardalis												
Nais simplex												
Nais variabilis										2	2	2.4
Piguetiella michiganensis	30	21	60.0	20	13	25.0	61	25	90.9	65	23	78.0
Stylaria lacustris												
Uncinais uncinata	10	10	20.0	30	14	37.5	4	3	6.1	8	4	9.8
Vejdovskyella intermedia				20	13	25.0				6	3	7.3
Total Tubificidae	1646	395	-	1626	372	-	614	158	-	1145	243	-
Immatures without hair chaeta	1414	341	85.9	1545	350	95.0	551	139	89.8	1067	226	93.1
Immatures with hair chaeta												
Aulodrilus pigueti												
Limnodrilus angustipenis	20	20	1.2				4	4	0.7			
Limnodrilus hoffmeisteri	71	36	4.3	10	10	0.6	18	9	3.0	20	9	1.8
Limnodrilus profundicola												
Limnodrilus spiralis	81	53	4.9	20	20	1.2	22	12	3.6	16	8	1.4
Peloscolex freyi	10	10	0.6				4	3	0.7	4	3	0.4
Peloscolex multisetosus longidentus												
Potamothrix moldaviensis	40	20	2.5	30	14	1.9	12	5	2.0	34	15	3.0
Potamothrix vejdovskyi	10	10	0.6	20	13	1.2	2	2	0.3	4	3	0.4
Stylodrilus heringianus	354	134	-	273	46	-	71	36	-	55	22	-
Enchytraeidae	91	51	-	566	84	-	22	12	-	158	45	-
Hirudinea												

Appendix 3. Continued.

Taxon	July 3 m Inner region $\bar{X}$	SE	%	3 m Outer region $\bar{X}$	SE	%	6 m Inner region $\bar{X}$	SE	%	6 m Outer region $\bar{X}$	SE	%
Total Naididae	747	420	-	10	10	-	4616	951	-	1222	146	-
Amphichaeta leydigii												
Chaetogaster diaphanus							101	68	2.2			
Chaetogaster diastrophus												
Dero digitata												
Dero pectinata												
Nais barbata	10	10	1.4									
Nais behningi	10	10	1.4									
Nais communis	10	10	1.4									
Nais pardalis				10	10	100.0				10	10	0.8
Nais simplex	10	10	1.4									
Nais variabilis	667	364	89.2				2161	758	46.8	91	34	7.4
Piguetiella michiganensis							1384	266	30.0	414	103	33.9
Stylaria lacustris	40	30	5.4				61	41	1.3	71	19	5.8
Uncinais uncinata							869	223	18.8	636	90	52.1
Vejdovskyella intermedia							20	20	0.4			
Total Tubificidae	10	10	-				444	254	-	51	24	-
Immatures without hair chaeta							414	226	93.2	51	24	100.0
Immatures with hair chaeta	10	10	100.0									
Aulodrilus pigueti												
Limnodrilus angustipenis												
Limnodrilus hoffmeisteri							10	10	2.3			
Limnodrilus profundicola							10	10	2.3			
Limnodrilus spiralis												
Peloscolex freyi							10	10	2.3			
Peloscolex multisetosus longidentus												
Potamothrix moldaviensis												
Potamothrix vejdovskyi												
Stylodrilus heringianus												
Enchytraeidae							10	10	-			
Hirudinea												

Appendix 3. Continued.

Taxon	July 9 m Inner region $\bar{X}$	SE	%	9 m Outer region $\bar{X}$	SE	%	12 m Inner region $\bar{X}$	SE	%	12 m Outer region $\bar{X}$	SE	%
Total Naididae	5555	1625	-	3878	356	-	4656	357	-	3444	400	-
Amphichaeta leydigii												
Chaetogaster diaphanus	131	65	2.4	101	26	2.6	222	56	4.8	253	76	7.3
Chaetogaster diastrophus							10	10	0.2			
Dero digitata												
Dero pectinata												
Nais barbata												
Nais behningi												
Nais communis	20	13	0.4									
Nais pardalis	10	10	0.2				61	31	1.3			
Nais simplex	10	10	0.2									
Nais variabilis	2444	947	44.0	424	113	10.9	263	60	5.6	121	31	3.5
Piguetiella michiganensis	636	158	11.5	1616	237	41.7	2343	340	50.3	1394	104	40.5
Stylaria lacustris	384	173	6.9	242	68	6.3	485	171	10.4	273	144	7.9
Uncinais uncinata	1050	229	18.9	1323	126	34.1	323	46	6.9	424	83	12.3
Vejdovskyella intermedia	869	472	15.6	172	51	4.4	949	116	20.4	980	287	28.4
Total Tubificidae	1485	447	-	3020	299	-	1717	422	-	5131	1183	-
Immatures without hair chaeta	1384	422	93.2	2828	238	93.6	1525	400	88.8	4303	1052	83.9
Immatures with hair chaeta										20	13	0.4
Aulodrilus pigueti												
Limnodrilus angustipenis				10	10	0.3				20	20	0.4
Limnodrilus hoffmeisteri	30	21	2.0	40	26	1.3	10	10	0.6			
Limnodrilus profundicola	10	10	0.7	10	10	0.3	30	14	1.8	10	10	0.2
Limnodrilus spiralis												
Peloscolex freyi	30	30	2.0	51	29	1.7	30	21	1.8	81	30	1.6
Peloscolex multisetosus longidentus	20	13	1.4				10	10	0.6			
Potamothrix moldaviensis	10	10	0.7	81	37	2.7	111	36	6.5	697	256	13.6
Potamothrix vejdovskyi												
Stylodrilus heringianus												
Enchytraeidae				91	26	-	303	56	-	374	89	-
Hirudinea							10	10	-			

Appendix 3. Continued.

Taxon	July: 15 m, Inner region $\bar{X}$	SE	%	15 m, Outer region $\bar{X}$	SE	%	All depths combined, Inner region $\bar{X}$	SE	%	All depths combined, Outer region $\bar{X}$	SE	%
Total Naididae	3363	614	-	1384	173	-	3788	492	-	1988	291	-
Amphichaeta leydigii				10	10	0.7				2	2	0.1
Chaetogaster diaphanus	152	58	4.5	141	40	10.2	121	27	3.2	99	24	5.0
Chaetogaster diastrophus	10	10	0.3				4	3	0.1			
Dero digitata												
Dero pectinata												
Nais barbata							2	2	0.1			
Nais behningi							2	2	0.1			
Nais communis	10	10	0.3				8	4	0.2			
Nais pardalis	61	38	1.8	51	40	3.6	26	11	0.7	14	9	0.7
Nais simplex							4	3	0.1			
Nais variabilis	91	34	2.7				1125	298	29.7	127	37	6.4
Piguetiella michiganensis	1111	268	33.0	152	56	10.9	1095	176	28.9	715	134	36.0
Stylaria lacustris	162	58	4.8	101	49	7.3	226	58	6.0	137	37	6.9
Uncinais uncinata	465	118	13.8	333	51	24.1	541	95	14.3	543	89	27.3
Vejdovskyella intermedia	1303	373	38.7	596	105	43.1	628	150	16.6	349	92	17.6
Total Tubificidae	6484	1721	-	3303	562	-	2028	550	-	2301	447	-
Immatures without hair chaeta	5626	1484	86.8	2716	510	82.3	1790	477	88.2	1980	384	86.0
Immatures with hair chaeta	51	19	0.8	51	19	1.5	12	5	0.6	14	6	0.6
Aulodrilus pigueti												
Limnodrilus angustipenis	30	21	0.5	61	27	1.8	6	5	0.3	18	8	0.8
Limnodrilus hoffmeisteri	91	21	1.4	71	29	2.1	28	9	1.4	22	9	1.0
Limnodrilus profundicola	40	20	0.6	20	13	0.6	18	6	0.9	8	4	0.4
Limnodrilus spiralis												
Peloscolex freyi							14	8	0.7	26	10	1.1
Peloscolex multisetosus longidentus				10	10	0.3	6	3	0.3	2	2	0.1
Potamothrix moldaviensis	404	119	6.2	222	64	6.7	105	37	5.2	200	69	8.7
Potamothrix vejdovskyi	242	129	3.7	152	71	4.6	48	30	2.4	30	17	1.3
Stylodrilus heringianus	667	327	-	4111	607	-	133	78	-	822	326	-
Enchytraeidae	424	98	-	566	132	-	147	40	-	206	52	-
Hirudinea	10	10	-	20	20	-	4	3	-	4	4	-

Appendix 3. Continued.

	October											
	3 m						6 m					
	Inner region			Outer region			Inner region			Outer region		
Taxon	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total Naididae				51	29	-				2192	488	-
<u>Amphichaeta</u> <u>leydigii</u>										677	230	30.9
<u>Chaetogaster</u> <u>diaphanus</u>												
<u>Chaetogaster</u> <u>diastrophus</u>												
<u>Dero</u> <u>digitata</u>				20	20	40.0				20	20	0.9
<u>Dero</u> <u>pectinata</u>				10	10	20.0						
<u>Nais</u> <u>barbata</u>												
<u>Nais</u> <u>behningi</u>												
<u>Nais</u> <u>communis</u>										10	10	0.5
<u>Nais</u> <u>pardalis</u>				10	10	20.0						
<u>Nais</u> <u>simplex</u>												
<u>Nais</u> <u>variabilis</u>				10	10	20.0				20	13	0.9
<u>Piguetiella</u> <u>michiganensis</u>										1454	330	66.4
<u>Stylaria</u> <u>lacustris</u>												
<u>Uncinais</u> <u>uncinata</u>										10	10	0.5
<u>Vejdovskyella</u> <u>intermedia</u>												
Total Tubificidae										283	128	-
Immatures without hair chaeta										273	132	96.4
Immatures with hair chaeta												
<u>Aulodrilus</u> <u>pigueti</u>										10	10	3.6
<u>Limnodrilus</u> <u>angustipenis</u>												
<u>Limnodrilus</u> <u>hoffmeisteri</u>												
<u>Limnodrilus</u> <u>profundicola</u>												
<u>Limnodrilus</u> <u>spiralis</u>												
<u>Peloscolex</u> <u>freyi</u>												
<u>Peloscolex</u> <u>multisetosus</u> <u>longidentus</u>												
<u>Potamothrix</u> <u>moldaviensis</u>												
<u>Potamothrix</u> <u>vejdovskyi</u>												
<u>Stylodrilus</u> <u>heringianus</u>												
Enchytraeidae										10	10	-
Hirudinea				10	10	-						

Appendix 3. Continued.

Taxon	October											
	9 m						12 m					
	Inner region			Outer region			Inner region			Outer region		
	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total Naididae	2717	615	-	2586	239	-	485	230	-	2172	477	-
Amphichaeta leydigii	10	10	0.4	182	61	7.0				10	10	0.5
Chaetogaster diaphanus												
Chaetogaster diastrophus												
Dero digitata	10	10	0.4	30	30	1.2						
Dero pectinata												
Nais barbata												
Nais behningi												
Nais communis												
Nais pardalis	20	20	0.7									
Nais simplex												
Nais variabilis												
Piguetiella michiganensis	2606	538	95.9	2363	189	91.4	465	230	95.8	2101	460	96.7
Stylaria lacustris												
Uncinais uncinata	51	51	1.9							10	10	0.5
Vejdovskyella intermedia	20	13	0.7	10	10	0.4	20	20	4.2	51	33	2.3
Total Tubificidae	263	103	-	2606	376	-	646	196	-	4626	369	-
Immatures without hair chaeta	263	103	100.0	2505	308	96.1	626	177	96.9	4495	338	97.2
Immatures with hair chaeta												
Aulodrilus pigueti				20	13	0.8						
Limnodrilus angustipenis												
Limnodrilus hoffmeisteri												
Limnodrilus profundicola												
Limnodrilus spiralis												
Peloscolex freyi												
Peloscolex multisetosus longidentus												
Potamothrix moldaviensis				81	69	3.1	20	20	3.1	131	43	2.8
Potamothrix vejdovskyi												
Stylodrilus heringianus												
Enchytraeidae	40	20	-	51	29	-	10	10	-	556	150	-
Hirudinea							10	10	-			

Appendix 3. Continued.

Taxon	October 15 m Inner region $\bar{X}$	SE	%	15 m Outer region $\bar{X}$	SE	%	All depths combined Inner region $\bar{X}$	SE	%	All depths combined Outer region $\bar{X}$	SE	%
Total Naididae	1737	419	-	677	263	-	988	246	-	1535	233	-
Amphichaeta leydigii							2	2	0.2	174	66	11.3
Chaetogaster diaphanus												
Chaetogaster diastrophus												
Dero digitata				40	20	6.0	2	2	0.2	22	9	1.4
Dero pectinata										2	2	0.1
Nais barbata												
Nais behningi												
Nais communis										2	2	0.1
Nais pardalis	10	10	0.6				6	5	0.6	2	2	0.1
Nais simplex				10	10	1.5				2	2	0.1
Nais variabilis										6	3	0.4
Piguetiella michiganensis	1687	426	97.1	475	243	70.1	951	234	96.3	1279	208	83.3
Stylaria lacustris												
Uncinais uncinata							10	10	1.0	4	3	0.3
Vejdovskyella intermedia	40	20	2.3	152	70	22.4	16	7	1.6	42	18	2.8
Total Tubificidae	3525	350	-	4030	456	-	887	261	-	2309	375	-
Immatures without hair chaeta	3353	359	95.1	3747	448	93.0	848	249	95.7	2204	357	95.4
Immatures with hair chaeta	10	10	0.3	40	30	1.0	2	2	0.2	8	6	0.3
Aulodrilus pigueti										6	3	0.3
Limnodrilus angustipenis												
Limnodrilus hoffmeisteri				20	13	0.5				4	3	0.2
Limnodrilus profundicola												
Limnodrilus spiralis												
Peloscolex freyi												
Peloscolex multisetosus longidentus												
Potamothrix moldaviensis	152	44	4.3	121	41	3.0	34	14	3.9	67	20	2.9
Potamothrix vejdovskyi	10	10	0.3	101	20	2.5	2	2	0.2	20	8	0.9
Stylodrilus heringianus	323	122	-	1828	785	-	65	33	-	366	199	-
Enchytraeidae	172	24	-	333	137	-	44	14	-	190	56	-
Hirudinea				20	13	-	2	2	-	6	3	-

Appendix 4. Mean densities (no. m^{-2}) for gastropod and pelecypod taxa collected during April, July, and October during 1981 in the inner (treatment) and outer (reference) regions at 3-15-m depths (n = 6) near the J.H. Campbell Plant, eastern Lake Michigan. In addition to mean ($\bar{X}$) and standard error (SE), gastropod and pisidia taxa in each region have been expressed as a percentage of their respective summed totals.

	April											
	3 m						6 m					
	Inner region			Outer region			Inner region			Outer region		
Taxon	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total Gastropoda												
Valvata sincera												
Amnicola limosa												
Bithinia tentaculata												
Lymnaea sp.												
Physella sp.												
Total *Pisidium*										10	10	-
Pisidium casertanum												
Pisidium compressum												
Pisidium conventus												
Pisidium fallax												
Pisidium henslowanum												
Pisidium lilljeborgi												
Pisidium nitidum nitidum										10	10	100.0
Pisidium nitidum pauperculum												
Pisidium variabile												
Others												
Sphaerium rhomboideum												
Sphaerium striatinum												

Appendix 4. Continued.

Taxon	April											
	9 m						12 m					
	Inner region			Outer region			Inner region			Outer region		
	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total Gastropoda	10	10	-	30	21	-	20	13	-	91	34	-
Valvata sincera	10	10	100.0	20	13	66.7				71	24	77.8
Amnicola limosa												
Bithinia tentaculata										10	10	11.1
Lymnaea sp.				10	10	33.3	20	13	100.0	10	10	11.1
Physella sp.												
Total *Pisidium*	51	40	-	81	30	-	192	111	-	576	78	-
Pisidium casertanum	40	30	80.0	20	20	25.0	111	48	57.9	242	59	42.1
Pisidium compressum										10	10	1.8
Pisidium conventus												
Pisidium fallax	10	10	20.0	30	14	37.5	51	40	26.3	192	33	33.3
Pisidium henslowanum												
Pisidium lilljeborgi												
Pisidium nitidum nitidum				30	21	37.5	20	20	10.5	81	34	14.0
Pisidium nitidum pauperculum										10	10	1.8
Pisidium variabile										20	13	3.5
Others							10	10	5.3	20	13	3.5
Sphaerium rhomboideum												
Sphaerium striatinum												

Appendix 4. Continued.

	April											
	15 m						All depths combined					
	Inner region			Outer region			Inner region			Outer region		
Taxon	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total Gastropoda	111	29	-	141	66	-	28	10	-	53	18	-
Valvata sincera	51	24	45.5	101	56	71.4	12	6	42.9	38	14	73.1
Amnicola limosa												
Bithinia tentaculata				20	13	14.3				6	3	11.5
Lymnaea sp.	60	22	54.5	20	13	14.3	16	7	57.1	8	4	15.4
Physella sp.												
Total _Pisidium_	879	109	-	1071	207	-	224	69	-	347	88	-
Pisidium casertanum	434	29	49.4	465	134	43.4	117	33	52.3	145	44	41.9
Pisidium compressum										2	2	0.6
Pisidium conventus	20	20	2.3	20	20	1.9	4	4	1.8	4	4	1.2
Pisidium fallax	162	30	18.4	222	62	20.8	44	15	19.8	89	23	25.6
Pisidium henslowanum	61	31	6.9	91	26	8.5	12	8	5.4	18	8	5.2
Pisidium lilljeborgi				10	10	0.9				2	2	0.6
Pisidium nitidum nitidum	162	49	18.4	192	77	17.9	36	15	16.2	63	21	18.0
Pisidium nitidum pauperculum										2	2	0.6
Pisidium variabile				61	38	5.7				16	9	4.7
Others	40	20	4.6	10	10	0.9	10	5	4.5	6	3	1.7
Sphaerium rhomboideum												
Sphaerium striatinum												

Appendix 4. Continued.

Taxon	July											
	3 m						6 m					
	Inner region			Outer region			Inner region			Outer region		
	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total Gastropoda							20	20	-			
Valvata sincera							10	10	50.0			
Amnicola limosa												
Bithinia tentaculata												
Lymnaea sp.							10	10	50.0			
Physella sp.												
Total *Pisidium*							20	20	-	10	10	-
Pisidium casertanum							10	10	50.0			
Pisidium compressum												
Pisidium conventus												
Pisidium fallax												
Pisidium henslowanum												
Pisidium lilljeborgi												
Pisidium nitidum nitidum												
Pisidium nitidum pauperculum												
Pisidium variabile												
Others							10	10	50.0	10	10	100.0
Sphaerium rhomboideum												
Sphaerium striatinum												

Appendix 4. Continued.

Taxon	July											
	9 m						12 m					
	Inner region			Outer region			Inner region			Outer region		
	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total Gastropoda	101	71	-	81	26	-	253	80	-	596	122	-
Valvata sincera	81	60	80.0	81	26	100.0	152	46	60.0	152	68	25.4
Amnicola limosa	20	13	20.0				20	20	8.0	152	26	25.4
Bithinia tentaculata												
Lymnaea sp.							71	36	28.0	293	48	49.2
Physella sp.							10	10	4.0			
Total *Pisidium*	51	19	-	465	91	-	828	100	-	960	139	-
Pisidium casertanum	10	10	20.0	91	34	19.6	212	71	25.6	303	66	31.6
Pisidium compressum							10	10	1.2			
Pisidium conventus												
Pisidium fallax				51	19	10.9	222	40	26.8	273	76	28.4
Pisidium henslowanum							20	13	2.4			
Pisidium lilljeborgi												
Pisidium nitidum nitidum				10	10	2.2	162	26	19.5	141	56	14.7
Pisidium nitidum pauperculum							40	13	4.9	71	36	7.4
Pisidium variabile				10	10	2.2				20	13	2.1
Others	40	13	80.0	303	72	65.2	162	56	19.5	152	49	15.8
Sphaerium rhomboideum												
Sphaerium striatinum				10	10	-				10	10	-

Appendix 4. Continued.

Taxon	July: 15 m: Inner region $\bar{X}$	SE	%	Outer region $\bar{X}$	SE	%	All depths combined: Inner region $\bar{X}$	SE	%	Outer region $\bar{X}$	SE	%
Total Gastropoda	232	33	-	384	91	-	121	29	-	212	53	-
Valvata sincera	131	29	56.5	273	60	71.1	75	19	61.7	101	26	47.6
Amnicola limosa	61	16	26.1	51	19	13.2	20	7	16.7	40	12	19.0
Bithinia tentaculata												
Lymnaea sp.	40	20	17.4	61	27	15.8	24	10	20.0	71	23	33.3
Physella sp.							2	2	1.7			
Total *Pisidium*	1525	229	-	2212	233	-	485	122	-	729	161	-
Pisidium casertanum	495	29	32.5	495	43	22.4	145	39	30.0	178	39	24.4
Pisidium compressum							2	2	0.4			
Pisidium conventus	61	31	4.0	141	71	6.4	12	7	2.5	28	17	3.9
Pisidium fallax	222	71	14.6	182	50	8.2	89	25	18.3	101	27	13.9
Pisidium henslowanum	81	13	5.3	202	82	9.1	20	7	4.2	40	21	5.5
Pisidium lilljeborgi				10	10	0.5				2	2	0.3
Pisidium nitidum nitidum	313	57	20.5	545	87	24.7	95	26	19.6	139	44	19.1
Pisidium nitidum pauperculum	51	29	3.3	51	24	2.3	18	7	3.8	24	10	3.3
Pisidium variabile	40	20	2.6	141	82	6.4	8	5	1.7	34	19	4.7
Others	263	76	17.2	444	46	20.1	95	26	19.6	182	37	24.9
Sphaerium rhomboideum				10	10	-				2	2	-
Sphaerium striatinum	61	31	-				12	7	-	4	3	-

Appendix 4. Continued.

Taxon	October											
	3 m						6 m					
	Inner region			Outer region			Inner region			Outer region		
	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total Gastropoda							20	20	-	121	44	-
Valvata sincera							20	20	100.0	91	34	75.0
Amnicola limosa										20	13	16.7
Bithinia tentaculata												
Lymnaea sp.										10	10	8.3
Physella sp.												
Total *Pisidium*							20	13	-	293	79	-
Pisidium casertanum										131	48	44.8
Pisidium compressum												
Pisidium conventus												
Pisidium fallax							10	10	50.0	61	27	20.7
Pisidium henslowanum												
Pisidium lilljeborgi												
Pisidium nitidum nitidum										40	30	13.8
Pisidium nitidum pauperculum												
Pisidium variabile												
Others							10	10	50.0	61	39	20.7
Sphaerium rhomboideum												
Sphaerium striatinum												

Appendix 4. Continued.

Taxon	October											
	9 m						12 m					
	Inner region			Outer region			Inner region			Outer region		
	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total Gastropoda	141	58	-	51	29	-	1111	545	-	424	294	-
Valvata sincera	121	38	85.7	40	20	80.0	697	321	62.7	202	132	47.6
Amnicola limosa							131	53	11.8	51	19	11.9
Bithinia tentaculata												
Lymnaea sp.	20	20	14.3	10	10	20.0	283	214	25.5	172	148	40.5
Physella sp.												
Total *Pisidium*	192	133	-	222	51	-	1525	546	-	697	107	-
Pisidium casertanum	71	48	36.8	57	24	22.7	283	85	18.5	172	45	24.6
Pisidium compressum				30	21	13.6						
Pisidium conventus	10	10	5.3				30	21	2.0	10	10	1.4
Pisidium fallax	10	10	5.3	61	27	27.3	667	262	43.7	152	38	21.7
Pisidium henslowanum							10	10	0.7	10	10	1.4
Pisidium lilljeborgi												
Pisidium nitidum nitidum				30	14	13.6	263	119	17.2	222	37	31.9
Pisidium nitidum pauperculum				10	10	4.5	40	26	2.6	10	10	1.4
Pisidium variabile												
Others	101	78	52.6	40	30	18.2	232	93	15.2	121	38	17.4
Sphaerium rhomboideum												
Sphaerium striatinum												

Appendix 4. Continued.

	October											
	15 m						All depths combined					
	Inner region			Outer region			Inner region			Outer region		
Taxon	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%	$\bar{X}$	SE	%
Total Gastropoda	535	226	-	212	78	-	362	135	-	162	64	-
Valvata sincera	404	206	75.5	162	73	76.2	248	87	68.7	99	32	61.3
Amnicola limosa	101	13	18.9	30	14	14.3	46	15	12.8	20	6	12.5
Bithinia tentaculata												
Lymnaea sp.	30	21	5.7	20	20	9.5	67	45	18.4	42	30	26.3
Physella sp.	•											
Total *Pisidium*	2808	840	-	1404	372	-	909	278	-	523	118	-
Pisidium casertanum	697	226	24.8	374	99	26.6	210	67	23.1	145	33	27.8
Pisidium compressum	20	20	0.7	10	10	0.7	4	4	0.4	8	5	1.5
Pisidium conventus	91	38	3.2				26	10	2.9	2	2	0.4
Pisidium fallax	343	120	12.2	111	57	7.9	206	73	22.7	77	17	14.7
Pisidium henslowanum	253	94	9.0	131	53	9.4	53	26	5.8	28	14	5.4
Pisidium lilljeborgi				10	10	0.7				2	2	0.4
Pisidium nitidum nitidum	859	362	30.6	485	180	34.5	224	94	24.7	156	49	29.7
Pisidium nitidum pauperculum	91	30	3.2	10	10	0.7	26	10	2.9	6	3	1.2
Pisidium variabile	20	20	0.7				4	4	0.4			
Others	434	123	15.5	273	54	19.4	156	44	17.1	99	23	18.9
Sphaerium rhomboideum												
Sphaerium striatinum	40	30	-				8	6	-			